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CSIRO PUBLISHING GARDENING GUIDES

GOOD GARDENS
WITH LESS WATER

KEVIN HANDRECK

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National Library of Australia Cataloguing-in-Publication entry

Handreck, Kevin, 1938–
Good gardens with less water/author, Kevin Handreck.
Collingwood, Vic.: CSIRO Publishing, 2008.

9780643094703 (pbk.)

CSIRO Publishing gardening guides

Includes index.
Bibliography.

Landscape gardening – Water conservation – Australia.
Drought-tolerant plants.

635.0994

Published by

CSIRO PUBLISHING
150 Oxford Street (PO Box 1139)
Collingwood VIC 3066
Australia

Telephone: +61 3 9662 7666
Local call: 1300 788 000 (Australia only)
Fax: +61 3 9662 7555
Email: publishing.sales@csiro.au
Web site: www.publish.csiro.au

Front cover (clockwise, from top right):
Leucospermum gerrardii; image by iStockphoto; *Stylidium elongatum*; terracing on a steep slope; Italian capsicums; image by iStockphoto; image by iStockphoto

Back cover (clockwise, from top right):
Drainage pipe; *Dryandra formosa*; Yates Tuscan planter; a potted agave; cherry tomatoes

Set in 10.5/14 Adobe ITC New Baskerville
Cover and text design by James Kelly
Typeset by Desktop Concepts Pty Ltd, Melbourne
Printed in Singapore by Imago

All illustrations in this book are by the author unless otherwise acknowledged.

Note: For simplicity, some trade names are used in the text of this book or can be seen on illustrations. No endorsement of these products is intended, nor is criticism implied of similar products that are not mentioned or illustrated.

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Grevillea 'Superb' is a showy cross between *G. banksii* and *G. bipinnatifida* that is best suited to warm temperate areas.

PREFACE

During the last 10 years or so, gardening in much of Australia has become more difficult. Water restrictions have progressively become more severe as drought has intensified its grip on all of our largest cities and their hinterlands. These restrictions have progressed from mild (watering allowed every second day or three times a week), through once-a-week watering via drippers – to, in increasingly large areas, bucket only, and in others, a total ban on the application of municipal water direct to the garden.

Gardeners might argue that these restrictions are unfair, as they do not always address water use by industry and within the home. But before you get too agitated, spare a thought for irrigation farmers, some of whom have had to watch their life's work die because their water allocation has been slashed.

Water shortages are likely to get worse in all parts of Australia except the far northern tropics as the global warming to which we all contribute bites harder. If we want to have the many benefits that gardens provide, we need to make the most of the water that is available to us. That means using ALL the water that is provided free to us via rain, and recycling to the garden as much as possible of the water that we use in our homes.

Almost every edition of every Australian newspaper has at least one article about water.

I want to show you how it is possible to have a lovely garden even when water restrictions are severe. The knowledge contained in this book, supplemented where appropriate with information freely available on the websites listed, will, I am sure, enable you to do this. I will show you that with a little thought and some effort, it is possible to have a beautiful garden almost anywhere in Australia even with the most severe restrictions on the use of water from municipal supplies.

There are several sets of characters in this book. The central character is water. It is essential to all life. Waters from different sources are not all created equal though; they come with different amounts of dissolved salts and sometimes other contaminants. One part of this book will show you how to assess water from different sources and how to use this information when you use these kinds of waters in your garden.

The characters of the second set are almost beyond counting. They are the many thousands of plants that you can choose from to produce the visible part of your garden. They will not thank you if you have put them in an environment they do not like. Life will be

easiest for you as their carer, and for them, if you have chosen only plants that like your soil and climate, and that manage with the amount and quality of water that you can provide to them.

Plants get most of their water from the medium in which they are growing. This growing medium will generally be a soil, sometimes natural, sometimes a blend produced by a soil supplier. It could also be a potting mix. To allow your plants to get the most out of the water you or rain provide to them, it is desirable that you understand something of the interaction between water and growing media. The third set of characters of this book is therefore soils and other growing media. Their ability to hold and supply water is fundamental to having a good garden, even with less water.

A couple of invisible characters support the others. These are air and light. The first is the source of carbon dioxide, without which there are no plants. The second provides the energy that is essential for plants to use carbon dioxide, take up water and grow.

There is of course another character – you, the gardener. It is you who will enjoy the garden that you have created out of water, plants and soil. It is you who may well have a longer and more satisfying life because of your efforts. It is you who will know that your garden is soaking up some of the extra carbon dioxide that is the major cause of the water shortages we are experiencing in Australia. You know that you are providing oxygen for yourself and others through the plants of your garden.

Enjoy your garden.

KEVIN HANDRECK
Managing Director, Netherwood Horticultural Consultants Pty Ltd, Adelaide,
and former CSIRO Soil Scientist

If only we had this much water in southern Australia! Victoria Falls, Zimbabwe–Zambia border.

ACKNOWLEDGEMENTS

This book was initiated by my publisher – Ted Hamilton – of CSIRO Publishing. I thank him for persisting against my initial reluctance and for his expert guidance. Retirement for both publisher and author is no barrier to accomplishment. This book could not have been produced without the help I received from many individuals and organisations. I am particularly indebted to the following.

Rob Bickford, CSIRO; Kate Blood, Department of Primary Industries, Victoria; Keith Bodman, Rio Tinto; Chris Brady, Bureau of Metereology (BoM), Adelaide; John Brennan, Water Corporation, Western Australia; Don Bromley, The Container Connection; Bruce Brooks, BoM, Adelaide; Bunnings, Mile End, South Australia; Jolyon Burnett, CEO Irrigation Australia; Butlers Irrigation, Adelaide; Bob Campbell, Sage Horticulture; Colin Campbell; Ian Chivers, Native Seeds Pty Ltd; Geoff Connellan; Geoff Cresswell, Cresswell Horticultural Services; Ken Cuming, Moisturematic Controls; Bianca Dimont, Department of Natural Resources and Water (DNRW), Brisbane; Tim Durham, Eynesbury; Sid Dyer, A2Z Planter Technology; Rodger Elliot; Kathy Errey, Payneham Plant Wholesalers; John Gransbury, Hydroplan; Cliff Hignett, Soil Water Solutions; Des Horton, City West Water; David Huett, New South Wales Agriculture; Daryl Joyce, University of Queensland; Jon Lamb, Jon Lamb Communications; Simon Leake, Sydney Environmental and Soil Laboratory; Lesley Lopez, *Burke's Backyard* Magazine; Tim Maguire, Toro Australia; Basant Maheshwari, CRC for Irrigation Futures; Don Marriott, Advanced Irrigation Consultants; John McDonald, Nursery & Garden Industry Queensland; Mitre 10, Malvern, South Australia; Tom Morley, DPI Victoria; John Neylan, AGCSA; Jann O'Connor, Irrigation Australia; Bob Patterson, Lanfax Laboratories; Chris Pfeffer, DNRW, Brisbane; Tony Robinson, Sydney Water; Therese Scales, Tikalara Designs; Chris Smith, Weathermatic Australia; Diana Snape; Richard Stirzaker, CSIRO; Nathan Syme, Jeffries; Greg Thomas, McCracken's Water Services; Tony Thomson, Department of Water, Land, and Biodiversity Conservation (DWLBC), South Australia; Thelma and Malcolm Vandepeer; Gerard White, Payneham Plant Wholesalers; Troy Whitmarsh, Reece Irrigation.

My special thanks go to my wife Eleanor, who critically reviewed the several drafts, and insisted that I write clearly and logically. No weasel words, marketing-talk or sloppiness were permitted.

KEVIN HANDRECK
Adelaide, September 2007

A major cause: people and their machines. (Photo: Ted Hamilton)

CAUSES OF WATER SHORTAGES

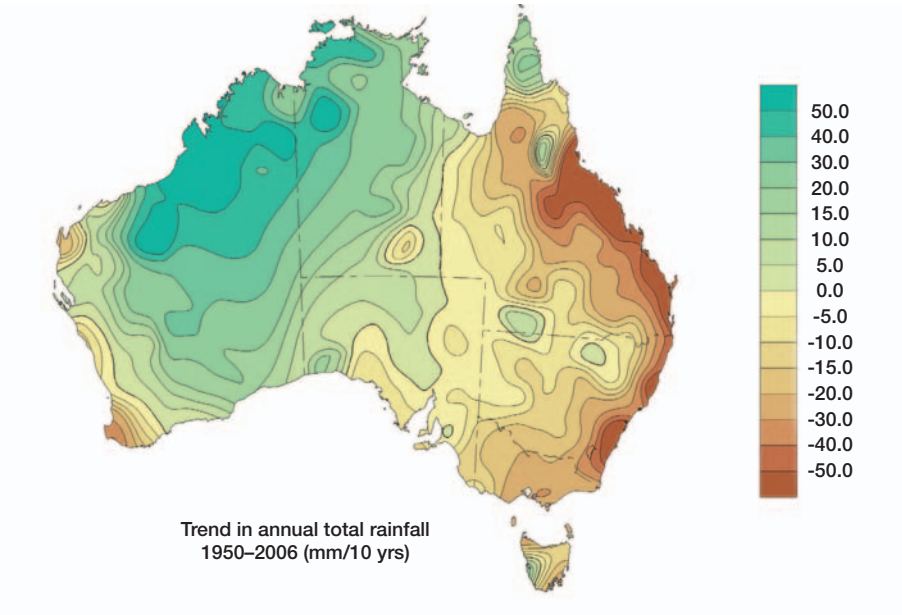
There are three major causes for the current restrictions on water use in our gardens.

The main cause is reduced rainfall, which in turn is due to the increasing concentrations of the greenhouse gases carbon dioxide, nitrous oxide and methane in the atmosphere. The carbon dioxide and nitrous oxide come from our burning of fossil fuels – coal, oil and gas – that produces the energy we use for heating and cooling, for running our appliances, and for powering our factories, vehicles and aeroplanes. The methane comes from rice paddies, cattle, rubbish dumps and, increasingly, from peat bogs as they thaw, and deep ocean deposits as ocean temperature rises. The higher the concentration of these gases in the atmosphere, the greater is the reduction in the loss to space of heat generated when the sun's rays hit the earth's surface. The resulting rise in the average temperature of the lower atmosphere increases evaporation of water. Water in the atmosphere is a powerful greenhouse gas, so the warming is further increased.

One result of increasing atmospheric temperature is that circulation patterns in the atmosphere shift. This means lower average rainfall across southern Australia, but increased rainfall in the tropics and in parts of central Australia (see the references listed in Appendix 1 for detailed information). Scientists have shown that when rainfall decreases by 10%, there is 30–50% decrease in runoff into streams and reservoirs. The trend towards decreased rainfall started about 25 years ago in south-western Western Australia and, more recently, in south-eastern Queensland, but it is now universal in southern Australia.

There is therefore a direct link between our use of energy and lower water levels in our reservoirs. And because Australians use more energy per person than do the citizens of any other industrialised country, we are major contributors to our lack of water. More widely, the combination of rising living standards throughout much of Asia and the Middle East, and rapidly increasing populations, is bringing billions of people in these regions up towards our energy use and greenhouse gas production levels.

A second cause of water restrictions is increasing population. At a local level, the combination of increasing population with



Australian rainfall trends, 1950–2006. (Bureau of Meteorology)

drastically lower water levels in reservoirs has an inevitable result.

A third cause is lack of vision by some politicians. The first warnings about global warming and its possible consequences were made by scientists nearly 40 years ago. Solid evidence has existed for at least 15 years, yet the leaders of countries whose citizens are the biggest polluters have taken little action until very recently. Even now, when the evidence is as solid as anything can be, much of the political response is nowhere near what is necessary to avert catastrophe for our grandchildren.

Some hopeful signs

Despite the size of the problem, there are many hopeful signs:

- decreased amount of water used in gardens, generally with minimal effect on plant quality
- voluntary reductions in energy use by increasing numbers of people
- general acceptance and practice of shorter showers and many other water-saving measures
- reduction of carbon footprint by parts of Australian industry
- small increase in the proportion of total energy production from wind, the sun, geothermal sources and waves
- phasing out of incandescent light bulbs
- improved energy efficiency in electrical appliances
- purchase of carbon offsets to plant trees and generate green energy
- some moves to require energy efficient design for new homes and other buildings

- slight decrease in average distance travelled by private car
- some increased use of public transport, motor scooters, bicycles and feet.

Gardens are a part of the cure

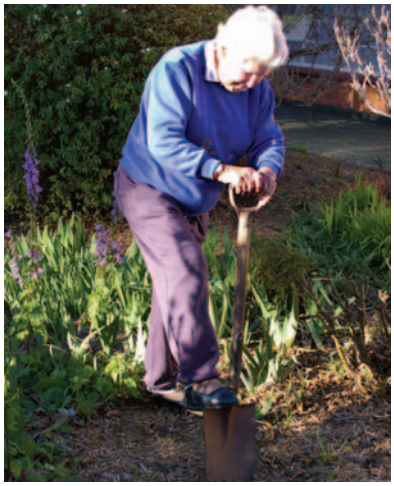
Gardeners make a significant contribution to reducing the effects of global warming. About 70% of the green cover in our cities is in home gardens. The main environmental effect of this greenery is that, by providing shade and natural evaporative cooling, it cools the area around our homes in summer, so reducing – even eliminating – the need for energy hungry air conditioning.

Our plants soak up carbon dioxide and release oxygen back into the atmosphere. Gardening broadcaster Colin Campbell has suggested that there should be an 'oxygen tax' imposed on non-gardeners!

Food produced in a home garden, even if it is only a few herbs and salad greens, saves the energy required to transport it from distant farms to local shops. Recycling of food scraps through compost bins eliminates the energy cost of taking them to a landfill. Time spent planting, trimming, weeding and sweeping by hand in the garden is time that might otherwise have been used in energy intensive activities such as driving or watching television.

Gardens are places for relaxing from the stress of modern life. Anyone who has visited the slums or 'concrete jungles' of many cities soon learns to appreciate the softening effect that living plants have on a cityscape.

Our cities do not have to become almost treeless, as in dusty Iqueque, Chile. (Photo: Eleanor Handreck)



Still enjoying gardening at 87.

Also, by creating a pleasant setting for their home, gardeners increase its value by up to tens of thousands of dollars. They create employment for at least 50 000 Australians through their purchases of plants, fertilisers, tools and landscaping services. They provide habitat for birds and other wildlife. And on average they live longer and healthier lives than non-gardeners.

So before you feel guilty about using some of your allocation of municipal water in your garden, think of all the benefits you are providing to yourself, your family, your community, our Earth.

PLANTS AND WATER

KEY POINTS

Types of plants
How to select plants that are suited to your climate, environment and soil
How to avoid plants that might become weeds
Water use and the three types of photosynthesis used by plants
Roots and mycorrhizal fungi
How plants get water and cope with drought
Fertilisers and water use
Phosphorus-sensitive plants

There are at least 420 000 different types of plants on our planet, of which at least 25 000 are native to Australia. Through the combined forces of changing climatic and environmental conditions (cooling, heating, drying, wetting, etc.), differing soil properties and genetic mutation, each existing plant is the product of an evolutionary process that has left it superbly adapted to a particular set of climatic and soil conditions. For a plant to grow well in our garden, we must provide it with conditions that are reasonably close to those its parents had in their natural environment. We can do this in two ways.

We can use large amounts of energy and water to modify our garden so that it is suitable for plants from very different environments. That is what we are doing in our attempts in Australia to reproduce the gardens of northern Europe. Restrictions on water use are doing to this style of gardening what catastrophe did to the dinosaurs.

We can grow those plants that are either indigenous to our area (the native plants of our area), or come from other areas, both within and beyond Australia, whose climates and soils are broadly similar to ours. For any given area in Australia, this still gives us many thousands of plants from which to choose. This style of gardening uses plants which, once established, will grow well and look good with little extra water than is provided by rain. Any extra water needed can come from water stored from runoff from

Pansy – an annual plant.

roofs and recycled from within the house. Much of any stored rainwater might well be used for producing fresh herbs, vegetables and fruit.

Types of plants

All plants fit into one of three categories:

1. Annuals grow from seed to producing seed to death within one year. Many garden weeds are annual grasses. Many of the bedding plants such as pansies, petunias and marigolds sold in garden centres are annuals. Shallow roots mean a need for frequent watering in dry weather. Water restrictions and the unwillingness of many gardeners to take the time needed to plant and maintain them have led to a rapid decline in their use in home gardens in favour of perennials.

2. Biennials need two years to complete their life cycle. They use the first year to produce the framework for the flowering of the second year. Parsley is an example.

Alternatives to drought-sensitive perennials (from top): *Pelargonium spinosum, Dryandra formosa, Darwinia macrostegia.*

3. Perennials grow for many years, often flowering and producing fruit or spores annually. In its broadest sense, this term encompasses all trees, shrubs, ferns, bulbous and tuberous plants, the many small herbaceous plants and the rhizomatous and tussock-forming grasses. In gardening circles

the term 'perennial' is generally restricted to refer to clumping herbaceous plants whose tops die back after flowering, but which grow new tops the following year.

Basic decisions

As a general rule, garden maintenance is easiest when perennials, in the broadest sense, form all or the larger part of the plantings.

There are several basic decisions to make when choosing perennial plants. One is to decide on the relative contributions that foliage and flowers will make to your garden. As the foliage of any plant will be present for a larger part of a year than will flowers, the colour, texture and form of foliage is a major consideration when choosing plants.

Another decision is about trees. A major benefit of trees in a garden is that the shading and cooling they provide reduces, even eliminates in some areas, the need to use energy hungry air conditioning. A second benefit is that trees enhance the appearance of your home. A major problem is that the garden areas around many new single houses and townhouses are too small to allow the growing of trees that will become very large when mature. In any case, such large trees will use so much water that smaller plants will need extra watering if they are to survive.

But you can have your cake and eat it. There are many trees, including the smaller eucalypts (see http://asgap.org.au/gallery.html) and increasing numbers of grafted eucalypts with guaranteed flower colours, that are of low to medium height (3–5 m) when mature. These can shade walls and outdoor living areas, and will not dominate descending layers of lower-growing shrubs.

The small *Eucalyptus dolichorhyncha* (was *E. forrestiana* ssp. *dolichorhyncha*) gives a spectacular year-long display and will fit into almost any garden. (Photo: Rodger Elliot)

You must also decide which trees need to be deciduous and which evergreen. Deciduous trees planted on northern and western sides of the house provide shade in summer, but let the sun warm the house in winter.

How plants cope with differences in water supply and evaporation potential

Many of the different forms that we see in plants have evolved in response to the amount of water available to them and/or to the ability of the air in their native habitat to evaporate water. Here is some information about the characteristics that have evolved in plants to enable them to thrive in six different climatic zones. This information will help you choose the kinds of plants that will thrive in your garden. Table 1 at the end of this section has a summary.

Plants with large leaves tend to come from constantly moist areas.

Climatic zones with ample water and low evaporation potential

At one climatic extreme are areas where annual rainfall is higher than annual evaporation potential and there are no very long dry periods. These include far northern latitudes, southern Chile, high-altitude areas elsewhere, and the wet tropics. The leaves of many plants in these areas are bright green, thin and often large. Leaf surfaces have large numbers of stomata, only a single layer of protective cells and the wax coating is thin. Many of these plants shed their leaves in winter in response to low temperature.

In gardens, plants with these characteristics must be continually watered during dry weather if they are to survive. Wherever in Australia there are severe restrictions on the use of water in gardens, and you cannot store enough in tanks, they have no place. When they die, or you decide to remove them, welcome the opportunity to plant some of the many spectacular plants that are more drought-tolerant.

Climatic zones with very high evaporation potential and little water

At another climatic extreme are the plants of areas like the Atacama desert of southern Peru and northern Chile (annual rainfall near zero, but some fog along the coast); the Namib desert (20 mm rain and 50 mm from coastal fog); the Great Karoo of South Africa (annual rainfall about 100 mm); Baja California and nearby parts of south-western USA. Annual evaporation can exceed 4000 mm. The plants of these areas are geared to rapid absorption of water when it arrives, and to hanging onto it. They may be cacti, whose leaves have been transformed into spines and whose fluted stems minimise heat load, have chlorophyll and hold large amounts of water.

Other water-storing plants are succulent. Some stem succulents have no leaves at all; photosynthesis takes place in their green stems. Other stem succulents can also produce short-lived leaves during the brief rainy season. In leaf succulents, the leaves are swollen and often globular or tubular so as to minimise surface area. In plants such as *Portulacaria afra*, crassulas and peperomias, both the leaves and stems are succulent. There are also root succulents and plants with combined stem and root succulence. Succulents and cacti are about 95% water. They can lose up to 70% of this water without damage.

Cacti and other succulents have shallow root systems so that they can gain most benefit from the occasional rains falling in their desert habitats. These shallow roots also allow the plants to use the often heavy dews of

Plants of extreme deserts (from top): *Echinopsis deserticola* cactus in the Atacama (Photo: Eleanor Handreck); 1500-year-old *Welwitschia mirabilis* in Namibia.

deserts and the water delivered by the coastal fogs of Namibia and the Atacama.

In gardens, once established, these plants need no water above that provided by rain. The soil must have excellent drainage, with **no** organic mulch. They may die if you get a very wet year.

Climatic zones with slightly more rain but still high evaporation rate

Annual rainfall in these zones might range from 100–450 mm, but annual evaporation is often in the 2000 to 3000 mm range. The plants have several types of adaptation to these slightly less extreme climates. Succulence is one, but leaves tend to be larger and less juicy than is common for plants of extreme deserts. Another adaptation is to disappear underground as bulbs or tubers during the dry season.

Plants from less extreme, but still dry, climates (from top): baobabs (*Adansonia grandidieri*) near Morondava, Madagascar, *Crassula rupestris* and *Mesembryanthemum*, from the Karoo and Namaqualand, South Africa, respectively.

The major adaptation to high evaporation rate is that leaves are small, even microscopic,

often vertically oriented, with high oil content, thickened, often rather woody, and with surfaces protected by several layers of cells that have thick waxy coatings or a dense covering of short hairs. The harsher the environment, the smaller and more woody are the leaves, and the lower their chlorophyll content. The reflective grey colour of leaf surface coatings reduces leaf heating and water loss. Stomata are often sunken into the leaf surface so as to further reduce water loss.

Plants of these areas are superbly attuned to finding water. An extensive network of near-surface roots make the most of rain when it does fall, but another vertical network extends 10–20 m, even to 50 m, to reach underground water. The grasses and other strappy-leaf plants (such as *Dianella*, *Lomandra* and Spinifex (*Triodia*)) of these dry areas are perennials with very extensive root systems. Access to water is enhanced by the wide spacings between the plants which win the competition for limited water. Some plants release chemicals from their roots or leaves that prevent other plants from growing near them. Many of these plants shed their oldest leaves as a last-resort response to extreme water shortage.

Thryptomene maisonneuvii; tough and showy. (Photo: Eleanor Handreck)

In some areas, such as the western slopes of Madagascar, the native trees lose all their leaves at the start of the long dry season. Of course, growth is non-existent during dry periods and slow when water is in short supply, but can be rapid after drought-breaking rains. Many of the plants of inland Australia have several of the above adaptations.

In gardens, plants with these types of adaptations to water shortage will generally grow well with no or minimal amounts of extra water. But if you plant them more densely than they would occur in their natural environment, and especially if you include trees that become large, you will inevitably need to supply more water than is delivered by rain. Note also that most of these plants need direct sunshine to flower well.

Mediterranean-type climatic zones

These areas are in the far south of South Africa, coastal central Chile, southern California, southern Australia, and all around the Mediterranean Sea. Rain falls mainly in the winter–spring period, and summers are long, hot and dry. Annual rainfall was around 500 mm, but is now less, and annual evaporation around 2000 mm. Plants have evolved to cope with long dry periods. Most of the plant characteristics described in the previous section apply to these plants too. Note that plants from higher altitudes in these areas will usually be less tolerant of dry conditions than those from lower altitudes.

Plants from these areas are well suited to the gardens of southern Australia. Many grow

Dryland plants from southern Africa (from top): *Protea exemia, Leucospermum gerrardii.*

well without extra water after establishment, but they also respond to modest amounts of extra water during the summer. But note the information in the box later in this chapter about the potential of some of them to become weeds.

Zones with dry climates, sometimes cold, sometimes hot

Many, but by no means all conifers (e.g. cypress, juniper, pine) evolved in areas that have a combination of cold winters, relatively low rainfall and long dry periods. Those with grey foliage have the greatest tolerance to drought. Other conifers (e.g. *Callitris*,

A dryland plant from seasonally cold areas: juniper.

Actinostrobus, *Widdringtonia*) evolved in drier areas and are generally fairly to highly drought-tolerant. Some roses come from these climatic zones and are reasonably drought-tolerant.

In gardens, quite a few of these plants manage on rain only so long as they are not planted too closely. But all will benefit from some extra water during the dry season.

Adaptation to cold, wet areas

A main adaptation of plants to the cold, often wet soils of high latitudes, and of the higher elevations of mountains closer to the equator, is to be low-growing. Plants from these areas are suited only to gardens in cold, high-rainfall areas.

As rainfall in southern Australia is likely to further decrease, it would be wise to choose plants that come from somewhat drier areas than that of your garden, unless of course you are able to supplement rain with tank water

Table 1. Rough guide to the drought tolerance of different types of plants

Plant characteristics	Tolerance to drought
Large leaves; thin leaves; native to northern Europe, northern North America, southern South America or the wet tropics	Minimal
Somewhat smaller leaves; from high altitudes in wet tropics or cool climates	Slight
Smaller leaves; leaves hairy, or grey, or hard, especially if they come from relatively dry areas	Probably moderately tolerant
Plants with fairly thick leaves; plants whose roots penetrate deeply into the soil; summer-dormant bulbous plants	Probably moderately to highly tolerant
Small to tiny leaves	Usually highly tolerant
Plants from inland Australia, including the dry tropics, with tiny, oil-rich leaves and/or hairy and/or grey (waxy) leaves. Plants from similar climatic zones elsewhere in the world	Usually highly tolerant
Succulents, cacti and other plants from extreme deserts	Highly tolerant

and greywater (see Chapter 6). If you cannot supply extra water to established plants, the plants you grow must be able to survive likely dry periods, whether that is two, four or six months without rain. (See Appendix 1 for sources of information about plants that are known to be suited to your area.) You are not restricted only to succulents, only to Australian native plants or only any other particular type of plant.

The basics of plants and water

The world of green plants is one of almost infinite variety. Just stroll through any botanic gardens, arboretum or garden centre to see a few of them. Pick up any book about plants that can be grown in gardens to see thousands more. Travel in spring through the richness of the sandplain flora of Western Australia.

Yet within this diversity run some common threads:

- (Almost) every plant has a top and a bottom. One exception are the 'air plants' (*Tillandsia* spp.).
- The top is usually at least partly green and is, in most plants, composed of leaves, stems, flowers and fruits.
- The bottom part – the roots – is usually hidden away in soil or some other growing medium, such as the organic litter in the cleft of a tree.
- Both tops and roots are essential. The decapitated roots of many plants (but not of *Wisteria* and poplar and other plants that 'sucker'!) soon die; tops alone either grow new roots or they die.

Tillandsia usneoides **(Spanish moss) manages without roots.**

Some of the many leaf forms (clockwise, from top left): *Syngonium*, thin, 150 mm; *Banksia audax*, thick and hard, 70 mm; *Dryandra tridentata*, hard, hairy, 26 mm; *Allocasuarina verticillata*, less than 1 mm; Lavender, grey, thickly mulched surface, 20 mm; *Callistemon* 'Little John', hard, 38 mm

INVASIVE GARDEN PLANTS

More than three-quarters of Australia's weeds were brought here by botanic gardens, plant collectors and the nursery trade for use as ornamental plants. Others were imported for use as pasture or crop plants and in forestry. Some weeds are Australian plants that have escaped from gardens in parts of the country outside their natural habitats. Others arrived as contaminants on imported goods (see www.weeds.org.au for lists of these weeds).

There is concern that as more gardeners switch to growing plants that are in tune with their local climate, even more plants will become environmental weeds. Potential weeds have one or more of the following characteristics. They:

- grow so well in your area without extra water that they out-compete other plants
- can colonise disturbed ground
- produce huge numbers of seeds, like daisies of all types and orchids such as African Weed-orchid or Monadenia (*Disa bracteata*)
- produce seeds that are easily dispersed by wind or water
- produce seeds that stick to clothing and animal fur
- produce fruits that are attractive to and spread by birds and animals such as foxes. Red fruits, as in bridal creeper, are particularly attractive to birds
- have two or more ways of reproduction (e.g. seed and bulbs) as in oxalis (soursobs)
- produce seeds that stagger their germination over many years ('hard-seeded'), as in Patterson's Curse (Salvation Jane)
- are not eaten by farm or native animals. Unpleasant smell from crushed leaves is often a reason for inedibility, as in bridal creeper and lantana
- have no insect or microbial predators.

Do not grow plants that are already recognised as weeds, or that have similar characteristics. The possibility of escape of potential weeds is least if you live in a heavily built-up city area, but the closer you live to bushland, waterways or open countryside, the more careful you must be in your choice of plants. In addition, do not dispose of garden waste by dumping it in bushland, along

Pretty?

Not when it (boneseed) out-competes native plants in bushland. (Photo: Rachel Melland)

Bridal creeper is smothering less bushland since the introduction of a fungal biological control agent.

roadsides or over the back fence. Rather, put it into a municipal green organics collection or compost it yourself. Use the above list to try to assess the weed potential of new plants you would like to grow. Much more information is contained in the fact sheets available at www.weeds.crc.org.au.

Another garden escapee – oxalis (soursob).

The purple peril – Patterson's Curse (Salvation Jane) takes over. (Photo: Tom Morley, DPI, Victoria)

- All plants have some means of reproducing themselves, either through spores (ferns) or seeds (other plants). Some also reproduce via offsets.
- Roots take water and nutrients for the whole plant from the growing medium around them.

Leaves – photosynthetic factories

The leaves are where much of the action of a plant takes place. They are held up towards sunlight so that they can use its energy to make sugars from the carbon dioxide of the air and from water. This process, called photosynthesis, also releases oxygen back into the atmosphere. The sugars produced by photosynthesis are the basic building blocks from which the whole plant is made. From them are produced the cellulose, lignin and hemicellulose of cell walls, the proteins of cell nuclei and seeds, the starches of potatoes and cereal grains, oils, vitamins, hormones, enzymes, perfumes, flower colours and so on.

Leaves are plants' sugar 'factories' (*Begonia* sp.).

The 'factories' within the leaves where photosynthesis takes place are called chloroplasts. They contain green pigments called chlorophyll. No chlorophyll means no photosynthesis, no plants on the surface of the earth, no oxygen in the atmosphere, and hence no insects, birds and animals (including us).

Also required for photosynthesis are the nutrients that are essential to all plants. Water and nutrients arrive in leaves from the soil through roots and stems. Carbon dioxide arrives through small holes or pores (stomata) in the outer, especially lower, surfaces of leaves. The carbon dioxide diffuses through stomata in much the same way as an odour moves from one room to another.

Inside the stomata, carbon dioxide passes through cell walls into plant cells that contain the chloroplasts. There, complex reactions, driven by sunlight and supervised by enzymes and nutrient elements, join carbon dioxide and water to form simple organic chemicals.

Plant growth rate can increase as the carbon dioxide content of the air increases. Vegetable growers often enrich the air inside their greenhouses from the current 380 ppm (roughly) carbon dioxide in the air to around 1000–1500 ppm. Do we conclude from this that the increasing concentration of carbon dioxide in the atmosphere from the burning of fossil fuels is going to be good for our plants? Generally no, because plant growth only increases if the plants have an ample supply of all nutrients **and are constantly well-watered.** The lower rainfall, higher temperatures and water restrictions resulting from global warming will, in most of Australia, prevent our plants from using the extra carbon dioxide.

Plant roots

'Out of sight' should not be 'out of mind' as far as plant roots are concerned. Of course, they are not as pretty as leaves and flowers, but a little study soon shows them to be equally fascinating.

Have a close look at the roots of the next weeds that you remove from your garden. Dig carefully and gently wash the soil from the roots. Note that some weeds have a strong, thick taproot from which thinner roots radiate into the soil. Others have a multitude of fine roots growing from the base of the above-ground parts.

Try to measure the total length of all of the roots of one plant. You will give up long before you get to the 630 km of roots once found on a large rye plant. When all the root hairs were included in the total, this one plant had a total root length of 11 000 km! And that did not include the huge network of

THREE TYPES OF PHOTOSYNTHESIS

C_3 photosynthesis This is the type of photosynthesis used by plants that evolved in temperate to cold climatic zones. It also extends to many plants of Mediterranean climatic zones. It works well when air temperatures are below about 30°C.

C_4 photosynthesis This type of photosynthesis is used by many tropical grasses such as sugar cane, corn, sorghum and the warm-season lawn grasses (see p. 120), but also by plants such as the salt bushes (*Atriplex, Rhagodia*) and Euphorbiaceae. It is more efficient than C_3 photosynthesis at using carbon dioxide. It is basically an adaptation that allows plants to thrive under high light, high air temperatures and limited water supply. C_4 plants are better able to cope with drought than are C_3 plants. Recent research has shown that some C_3 plants also have some chloroplasts that use the C_4 method.

In both C_3 and C_4 photosynthesis, light and carbon dioxide must both arrive at the chloroplasts at the same time. This means that the stomata of these plants must open during the day. A down-side of this is that water is constantly lost from the open stomata.

CAM (crassulacean acid metabolism) Plants that use this method of photosynthesis open their stomata at night, when the air is cooler and more humid than during the day. Water loss through them is reduced to a minimum. The carbon dioxide that enters at night is converted into acids (like the malic acid that gives green apples their sharp taste) which are stored until the next day. During the day, carbon dioxide is released from these acids inside the plant and converted to sugars. CAM is used by the many succulents and cacti that are superbly adapted to growing in seasonally very dry environments where day temperatures are high and night temperatures often very low. Cacti and succulents therefore make excellent plants for gardening without extra water.

C_4 photosynthesis in action: kikuyu lawn.

Stem succulent: *Pachypodium rosulatum* var. *gracilius*, Madagascar.

Masses of roots are needed to anchor trees against rivers swollen by monsoonal rain.

mycorrhizal fungus hyphae growing with the roots (see p. 20).

All roots:

- anchor the plant in the soil. They have to hold it against strong winds and grazing animals
- collect water and mineral nutrients from the soil.

In addition, some roots:

- store nutrients, particularly phosphorus, for later use by the whole plant (most perennial plants)

Potatoes on sale at their source in Peru.

- store food, for the plant's later use (as in carrots) or for the next generation (as in potatoes)
- store water (as in dahlia and bridal creeper).

Size of root systems

You would expect that the larger a plant, the more extensive will be its root system. That is generally true, but there are many variations on this theme.

Most of the roots of the plants we grow in our gardens are in the top 30–50 cm of soil, but many plants also push roots more deeply if the soil is moist.

Many trees and shrubs that are adapted to seasonal drought have roots that extract water from 10–12 metres below the surface.

The widespread spinifex (*Triodia* spp.) of arid Australia can send its roots down 50 m.

The roots of most trees extend horizontally well beyond the ends of their branches. Often about 60% of the total root system of large trees is outside the 'drip circle'. A large tree in a garden can suck water from all of the rest of the garden, making it nearly impossible to grow other plants. It is virtually impossible to have a thriving vegetable garden when the soil is laced with roots from nearby trees.

The seedlings of plants from seasonally dry environments produce roots more rapidly and more extensively than those of plants from less harsh environments. This enables them to contact enough water to get them through their first dry season.

Surface roots take up nutrients being recycled from decaying leaves, and bind the soil.

The shallow roots of citrus need to be protected – here by weedmat and coarse bark mulch. Drippers are below the weedmat.

Roots that grow deep into the soil recycle back to the surface nutrients that have leached from the surface in drainage waters. An ecologically balanced garden will have at least some deep-rooted plants.

The roots of warm-season lawn grasses such as couch and kikuyu can push roots down 2 m if their tops are not cut too short. In contrast, the roots of cool-season lawn grasses such as the bent grasses penetrate no more than 30 cm (see p. 121). Even the roots of tall fescue – the most drought-tolerant cool-season grass – barely penetrate to 1 m, and a lot less if it is closely mown.

Eucalypt roots, shown exposed in a road cutting, often extend to deeper than 10 m into the soil.

Light to moderate pruning during the growing season reduces root growth for several months. One consequence of this is that young non-dormant trees should not be pruned at transplanting, as this is a time when as much root growth as possible is desirable.

Digging under and near shrubs and trees damages their roots and will reduce their ability to take up water. Never disturb the soil under shallow-rooted trees such as avocadoes and citrus.

Roots need oxygen

Roots must have a constant supply of oxygen. Yes, they breathe just as we do. For most plants, this oxygen comes from the air direct to their external surfaces via the pores between soil particles. Oxygen supply will be best when the soil has excellent structure (see p. 34) and when the larger pores are not filled with water. Oxygen moves only very slowly through the still water held in the

WHY ARE MYCORRHIZAL FUNGI USEFUL?

Plants have extensive root systems, but these systems are enormously extended by the strands of the mycorrhizal fungi that grow from the roots of at least 80% of all plants.

- The spores of these fungi germinate on the outside of young roots, invade root cells, but then live in harmony with their host plant. The fungi then grow long strands called hyphae out into the soil. Fungal hyphae are very thin, so it takes less energy to grow a given length of them than it does to grow the same length of root.
- The plant feeds sugars to the fungi; the fungi increase the supply of nutrients – particularly phosphorus and zinc – and water to the plant in a way that is much more efficient than if the plant did it by growing more roots.
- The extra water increases the plant's tolerance of drought and high temperatures.
- The small proportion of plants that do not form liaisons with mycorrhizal fungi include the crucifers (cabbage, cauliflower, turnips, mustard, wallflower, candy tuft, stocks, horse radish) and the saltbushes.
- Many of the toadstools and mushrooms that can be seen in pine forests are the fruiting bodies of mycorrhizal fungi that are living in harmony with the trees.
- Orchid seeds will germinate only when they are in contact with special types of mycorrhizal fungi.

Mycorrhizal fungus growing in association with roots.

pores of a waterlogged soil. The rates of movement of oxygen through air and water are as different as the speeds of a slow tortoise and a jet aircraft. Plants that grow in water (e.g. rice, reeds) are able to supply oxygen to their roots through their leaves and stems.

Reeds being used to purify runoff water at Bau Farm Nursery. (Photo: David Huett, NSW Agriculture)

Other facts about roots

Over half of all the organic matter produced during photosynthesis ends up in the growing medium, either as dead pieces of roots, or as root exudates, which are discharges from roots. This organic matter provides a rich diet

Iron deficiency symptoms in a *Grevillea*, caused by high soil pH.

for countless millions of micro-organisms that protect the roots against pathogens, and help root growth through the hormones they produce.

Plant roots take up nutrient elements by absorbing them from the water in the soil, which is called the soil solution. The actively growing cells near root tips and in the root-hair zone select the nutrients needed by the plant. Bringing the nutrients into the plant uses oxygen and expends energy.

All this is quite easy if there is plenty of each of the nutrients in the soil solution. But sometimes the concentration of one or more nutrients is too low to satisfy the needs of the plant. Faced with a shortage, many plants are able to modify the soil immediately around their roots. They exude various chemicals that are able to dissolve nutrients from soil minerals.

For example, the roots of plants that evolved to grow in calcareous or alkaline soils exude acid and chelating compounds in response to a shortage of iron. Plants that are not able to do this (e.g. rhododendrons, camellias, many hybrid grevilleas) show symptoms of iron deficiency (yellowing of the youngest leaves) when they are grown in the same soil.

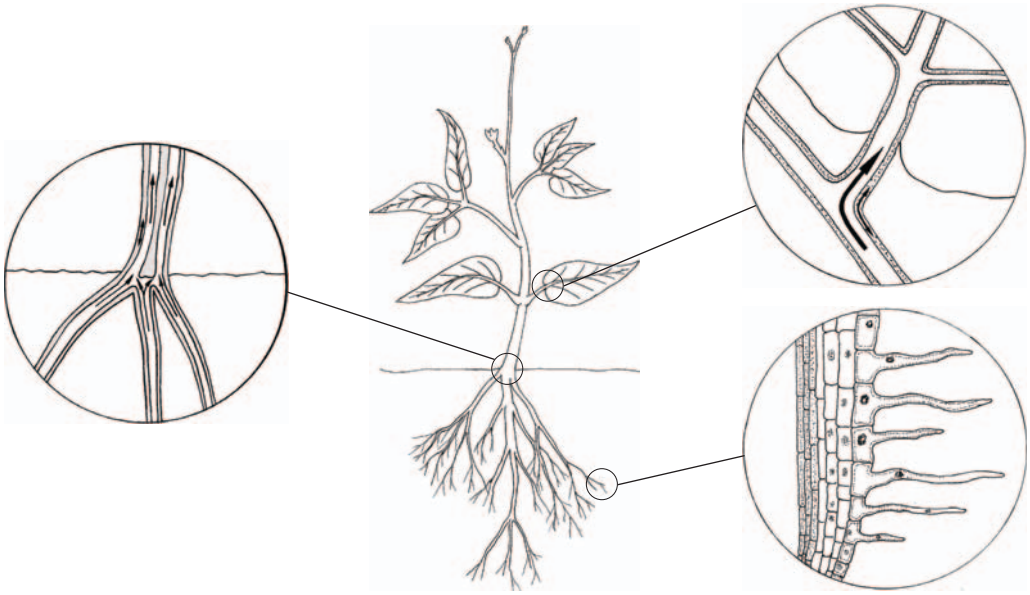
Transpiration: the evaporation of soil water through plants

One way of thinking of a plant is to imagine it as a bundle of flexible narrow tubes running from root surface to leaf surface. The tubes are filled with water.

The bottoms of most of these tubes end in root hairs, which are long cells that protrude profusely from near the tips of growing roots. The top ends of the tubes end in structures called stomata. These start to close as the leaf around it gets a bit dry (seen as wilting), or when a signal from the bottom end tells it that there is not enough water left in the soil to fill the tube.

When stomata are open, water is evaporated through them into the surrounding air. This evaporation of water is called transpiration. Transpiration creates a suction in the water-filled tubes inside the plant. This suction draws more water up through the plant and from the soil around its roots in much the same way that sucking on a straw raises iced coffee from a carton.

The rate of transpiration increases with an increase in air temperature and wind speed, and with a decrease in air humidity. Therefore, plants use water most rapidly on hot, windy, dry days. Transpiration keeps the plant cool, but it also means that plants must continue to have access to water if they are to survive.



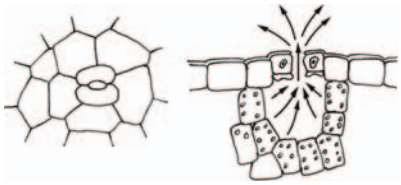
Path of water through a plant.

Temperature and water use

It is obvious, but has to be stated: as temperature increases, plants lose water more rapidly. Evaporative cooling is the only way they can keep cool. For example, in air with a relative humidity of 70%, a 5°C rise in leaf temperature doubles the transpiration rate. This is particularly important for potted plants (see p. 140).

Effects of water stress on plants

Plants grow at their best when the temperature and amount of light are right for them, and they are never short of nutrients and water. A shortage of water causes stomata to partly or totally close, so that water loss through transpiration is reduced or stopped. This also reduces or shuts off the supply of carbon dioxide and so reduces or stops the manufacture of the sugars that are essential for growth. The more severe the water deficiency and the longer it lasts, the greater will be the reduction in plant growth. Prolonged lack of evaporative cooling will cause leaf temperature to rise high enough to kill leaves.



Stomata.

Flowering and fruit production are particularly hard hit by lack of water. If you do have to make a choice about where to reduce water use in your garden, don't skimp on vegetables and fruit trees. Drought causes lettuce and other leafy vegetables to flower prematurely, tomatoes to develop blossom

end rot and cucumbers to become bitter. Fruit trees may drop much of their fruit.

Some benefits of water stress

We can use water stress to our advantage in our gardens. Allowing established ornamental plants to become moderately water stressed is a highly effective way of keeping garden water use to a minimum (see below and p. 74). Stress also prevents excessive growth, thus reducing the need for thinning and cutting back. Disease problems often found in over-wet gardens are reduced. Mild water stress during the later stages of ripening reduces fruit size and so improves quality. Rotting of soft fruits is lessened.

How plants deal with a shortage of water

If there is plenty of water in the soil, the water in the largest pores is easily pulled from the soil by transpiration. But as more water is removed from the soil, the remaining water is held more and more firmly in progressively smaller pores, so that it is increasingly difficult for the plant to extract water from the soil.

Eventually, the plant is unable to extract water fast enough from the soil to make up for transpiration losses. Stomata close, but there is still some water being lost from leaf surfaces. This is a universal response amongst plants, but what happens next to the plant depends on how drought-tolerant it is.

The thin leaves of drought-sensitive plants wilt, curl and hang vertically. These changes reduce total effective leaf area and hence the amount of heat reaching the plant. At first these plants may wilt only briefly during the hottest part of the day and will recover around sunset, when transpiration is further reduced to below the rate at which water is taken up from the soil. If drying of the soil continues, the period of wilting starts earlier in the day and lasts longer. Eventually the point is reached where daytime losses of water cannot be made up at night. Wilting becomes permanent. The plants begin to wither and die. The soil at this point is said to be at 'permanent wilting point' (see p. 51 for more information).

Death eventually follows wilting if more water is not supplied.

The response of drought-tolerant plants is different. Their leaves have thick outer cell layers, waxy and hairy coatings, and fewer and sunken stomata, which together allow them to drastically cut water losses when soil water becomes scarce. The hard, woody nature of their leaves also prevents them from drooping in the manner of drought-sensitive plants. But with a continuing decline in water supply, they eventually start to lose older leaves as a means of extending the supply to vital

The leaves of this correa looked like this at the end of summer, but quickly recovered after the first autumn rains.

younger leaves. Towards the end of a dry summer, many drought-tolerant plants do look yellowish and droopy, but they get back to their former glory within a couple of weeks of rain.

But in addition to these strategies in the leaves, drought-tolerant plants are also able to continue to extract water from soils that have dried to the permanent wilting point of drought-sensitive plants. Drought-tolerant plants are able to use more of the water in a soil than can drought-sensitive plants (see p. 51 for further information).

Fertilisers and water use by plants

This book is about water and garden plants. It was tempting to exclude any information about fertilisers, but the fact is that there are close links between the level of nutrient supply to plants, the amount of water they use and the way they respond to drought. Here are some facts (see p. 145 for more information about potted plants, and p. 128 for more information about lawns).

Plants such as vegetables and fruit trees that must keep growing vigorously if they are to fulfil their purpose must be fed. This also applies to bedding plants and to perennials such as roses whose blooms are harvested and that are pruned every year. Detailed information is given in *Gardening Down-Under* (see Appendix 1).

The fertiliser situation is quite different for perennial ornamental plants in garden soils. They need much less than do vegetables, etc., and usually none once they are established.

To get adequate early growth of ornamental plants, you will usually need to feed them at planting. Insert a plant pill or about two tablespoons of long-term controlled-release fertiliser into the soil at the bottom of the planting hole. This initial application should be skipped if the soil has a long history of fertiliser applications. For most Australian native plants and exotics from Mediterranean and drier climatic zones elsewhere, that will probably be all the fertiliser that is needed (see below for information about phosphorus-sensitive plants). This applies equally to organic and inorganic fertilisers. The soil itself and

recycling from fallen leaves will usually provide all they need once they are established.

You can easily wreck the superb adaptation of drought-tolerant plants to low water supply if you apply more than a small amount of fertiliser at planting. Drought-tolerant plants have evolved to grow on soils that have no more than modest supplies of nitrogen (from soil microbes and leguminous plants that grow within their communities), but low to sometimes extremely low concentrations of phosphorus. The softer, more rapid top growth allowed by repeatedly supplying these plants with extra nitrogen and phosphorus will cause them to use water faster. The fertiliser may reduce root growth and reduce or even eliminate the growth of mycorrhizal fungi on plant roots, so drought tolerance is reduced. It is best to allow these plants to remain hardy by letting them grow at their own natural pace.

However, there are two situations in which drought-tolerant plants might need some extra fertiliser after planting. One is if the soil is so deficient in nutrients that the initial application is not enough to produce good growth. The other is when you prune these plants and remove the prunings from under them. You may then need to apply extra fertiliser to replace the nutrients lost in the prunings.

You must never apply fertiliser to established plants if you cannot supply water to them.

Mulches that have been enriched with nutrients should not be used around drought-tolerant or phosphorus-sensitive plants (see box on next page). Restrict their use to fruit trees, vegetables and perennials from which foliage or flowers are frequently cut.

See the comments on p. 61 about not using laundry detergents that contain phosphorus if you want to apply greywater to your garden.

Eucalypt seedlings evolved to exploit the phosphorus in ashbeds created by fire. They need a small early supply in pots and gardens. Left to right: Same nitrogen, increasing phosphorus from zero. But see pp. 61–63 for the effects of excessive later supply.

PHOSPHORUS SUPPLY

If you have any connection with farming, you will know that farmers have to apply phosphatic fertilisers such as superphosphate to ensure adequate crop growth, because most Australian soils naturally had too little for exotic food crops and pasture plants. Nitrogen is also now widely applied, especially to cereals. While there may be a need for some trace elements, it is often nitrogen and phosphorus supply that determines crop yields.

This also applies to most garden soils; it is nitrogen and phosphorus that determine the growth of garden plants. Plant leaves and flowers typically have phosphorus concentrations that are about 15% of their nitrogen concentrations. Put another way, the ratio of phosphorus (P) to nitrogen (N) in the leaves (the P/N ratio – P concentration divided by the N concentration) will be about 0.15. As a general rule therefore, the fertilisers we use in gardens should also have nitrogen and phosphorus in this ratio. Only where a garden is being established on non-farmed soil might there be an early need for extra phosphorus.

You can easily check the P/N ratio of fertilisers. Take a calculator to the garden centre and do the following calculation. Look on the package for the listing of nutrients. Divide the concentration of total phosphorus by the concentration of total nitrogen (to give the ratio P/N).

For example, if a fertiliser contains 15% nitrogen (N) and 2% phosphorus (P), its P/N ratio is $2 \div 15 = 0.13$. This is about the ratio in which many plants take up these two nutrients. Most fertilisers, notably those based on poultry manure and some soluble powders, have much higher proportions of phosphorus. Their repeated use will allow excessive build-up of phosphorus in your soil to the point that it can harm your plants.

Most Australian native plants require moderate amounts of phosphorus for normal growth. The comments given above about fertiliser use at planting and later apply equally to all of these plants. However, there is a group of plants that are harmed or killed if they are given the amounts of phosphorus required by other plants. These are the so-called 'phosphorus-sensitive' plants. The soils of their native habitats have extremely low concentrations of phosphorus, so these plants have evolved mechanisms that are highly efficient at extracting phosphorus from such soils and for conserving it within their structures.

Native vegetation growing on deep sands at Dark Island, South Australia, was decimated by the application of phosphorus.

Phosphorus toxicity symptoms in an acacia seedling.

Many species in the Australian proteaceous genera such as *Banksia, Telopea* (waratah), *Grevillea, Isopogon, Dryandra, Hakea,* and in southern African genera such as *Protea, Leucospermum* and *Leucadendron,* are especially efficient at extracting phosphorus from soils. Application of a phosphatic fertiliser to soils in which these plants are to be grown is a sure way of killing them through phosphorus toxicity and/or iron deficiency. Death will be surer and more rapid in sandy soils than in heavier soils.

Non-proteaceous genera known to contain species that are prone to phosphorus toxicity include *Acacia*, *Bauera*, *Beaufortia*, *Boronia*, *Bossiaea*, *Brachysema*, *Chorozema*, Daviesia, *Eutaxia*, *Hypocalymma*, *Jacksonia*, *Lechenaultia* and *Pultenea*.

Any fertiliser applied to these plants must have a P/N ratio of less than 0.1, and preferably less than 0.07. For most gardens, the only fertiliser needed by these plants will be a little urea (N only). A few might benefit from a little extra potash (K), as from potassium sulphate, on very sandy soils. These phosphorus-sensitive plants **must not** be fertilised with poultry-manure-based products or blood and bone. Nor must they be watered with greywater that contains phosphorus (see p. 61). If you find that in your garden any of the phosphorus-sensitive plants listed above become yellow, grow poorly or die, the cause is probably large past applications of phosphorus. If this is confirmed by soil analysis, you will have to grow less-sensitive plants.

It is essential that you understand that the majority of Australia's native plants are **not** sensitive to phosphorus. Those from rain forests, both cool and tropical, are rarely sensitive. Those in the Myrtaceae family (eucalypts, corymbias, callistemons, melaleucas, *Leptospermum, Kunzea, Calytrix, Darwinia, Thryptomene*, etc.) are usually not sensitive. Those from alkaline (high pH) soils are rarely sensitive. All of these non-sensitive plants can receive the same early application of fertiliser as listed above for general ornamental plants. But note the remarks about the effect of fertilisers on drought tolerance.

Patterns in the soil. (Photo: Eleanor Handreck)

KNOW YOUR SOIL

KEY POINTS

Getting to know your soil

Soil texture and soil structure

Improving sandy soils

When to use gypsum

The main aim of this chapter is to enable you to maximise the retention of water by your soil and hence its ability to supply water to your plants. The first step is to find out a little about what soils are made of.

We see in road cuttings, excavation sites and cultivated fields that there is not just one uniform covering of soil across our planet. Soils in different areas look different from one another. They have different colours, the way their particles are fitted together is different, and they feel different when we rub them with our fingers. But despite these differences, all soils have five main components:

1. Inorganic particles – minerals that have been produced from rocks by weathering, together with unchanged particles of rock.
2. Organic materials – humus, and the dead and decaying parts of plants and soil animals.
3. Water – the 'soil solution', in which nutrients for plants are dissolved.
4. Air – which fills the spaces between soil particles that are not filled by soil solution.

Natural soils often vary in colour and other properties with depth.

5. Living organisms – ranging in size from small animals to viruses.

Soils look and feel different because:

- they have different proportions of the above components
- the components are grouped together in different ways
- there are many different types of minerals, and each soil has different proportions of them
- the mineral fractions of different soils contain widely different proportions of large and small particles.

Our look at road cuttings and excavation holes will have shown that the soil changes in appearance with depth. The surface soil – topsoil – usually has a darker colour than that below because of the humus (decomposed organic matter) in it. Below that – the subsoil – you may see several layers that differ in colour and/or other appearance and feel. In many gardens, the 'topsoil' is in fact not the natural soil of the area. It is a soil blend that has been produced by a soil supplier and spread over the subsoil. The soil in established gardens will have been changed over the years through additions of mulches, compost and fertilisers.

Look closely at the soil of your garden … including its wildlife!

Get to know the soil in your garden

Go into your garden and dig up a 20 cm deep block of soil of spade width and about 5 cm thick.

1. Is the soil easy or hard to dig? (Dry soil is harder to dig than moist soil. Soils with poor structure (see below) are harder to dig than are soils with good structure.)

Put the block of soil on a sheet of newspaper.

2. Is there a mulch layer on the surface?
3. Is the soil moist or dry? (Areas of dryness in soil that has recently received rain or irrigation might be due to water repellence.)

Look at the topsoil.

4. Can you see a layer of topsoil above soil of different appearance?
5. What differences in appearance can you see between the topsoil and the soil below it?
6. If the topsoil is very different from the soil below, does the topsoil look like a sandy soil blend from a soil yard?
7. Is there any builders' rubble or other junk between the topsoil and the subsoil?

Smell the soil.

8. Does it smell pleasantly 'earthy' or are there other smells coming from the soil, especially the lower part of the block? (Sour smells often indicate poor drainage.)

Look closely at exposed surfaces of the block of soil.

9. Can you see any differences in the appearance of the soil other than colour? (You may be seeing differences in soil texture or soil structure.)
10. Has the block already fallen apart, or is it still more-or-less in one piece? (Falling apart might mean that the soil is sandy or that it has a loose, friable structure.)
11. Are roots visible in all surfaces?
12. Can you see any other layers of soil as you go down the block? (Layers might have been formed naturally, but more often in gardens they have been produced during cleaning up after building or by an incompetent landscaper.)
13. If there are layers, do they look quite dense (compacted) or are they loose? (A compacted layer could mean that water and roots are not able to penetrate deeply into the soil, so plants have only a limited supply of water. Fine soil over a courser sandy layer will remain saturated after rain.)
14. Is the whole block just one mass of soil or does its surface have a fine crazing of fractures that divide it up into small crumbs that are still held together? (You are looking at the structure of the soil, which tells you much about how easily water drains through it and how much water it can hold for plants.)
15. Can you see any large holes in the soil that might have been formed by earthworms chewing their way through it?

Gently poke the soil with a knife or piece of stick.

16. Is it easy or difficult to break apart?
17. Does the topsoil behave differently from that below it? (Topsoils with ample amounts of organic matter will be more friable than the subsoil below. But some topsoils form crusts that impede water movement into the soil. See Chapter 5.)

Now take a couple of tablespoons of topsoil. Place the soil in the palm of one hand and rub some of it between a finger and thumb of the other hand.

18. Is it easy or difficult to break up the clods and crumbs? (Hard clods could mean that the soil is 'sodic' and so in need of an application of gypsum to increase its ability to hold and supply water to plants.)

Now determine the texture of your topsoil. Soil texture is about the sizes of particles in the soil, and the proportions in which they are present. You determine texture by working the

HOW TO DETERMINE SOIL TEXTURE

Moisten some of your soil in your hand with a little water.

1. Does the water instantly wet the soil or does it sit on the surface until you start mixing the two? (Water repellence in soils calls for correction by you.)

Knead the moist soil with fingers and thumb. As you knead it, add more water as needed to keep it moist, but not sloppy.

2. After a minute or two of working, does the soil still feel and sound gritty or does it now all feel smooth? (Grittiness indicates that the soil contains sand. Absence of grittiness indicates that all particles are smaller than sand size.)
3. Does it feel sticky and slippery? (If so, the soil has a high clay content.)
4. Does it have a silky feel? (A silky-smooth feel shows that the soil contains many particles of silt size.)
5. If the soil dries out a little during kneading, does it become very tough to work, or does it just fall apart? (Toughness indicates a high clay content and possibly a need for gypsum. Falling apart indicates a high sand content.)

Form the moist soil into a ribbon by squeezing it between fingers and thumb. Note the length of the ribbon that you can form before it breaks apart.

Use Table 2 to interpret what you have felt and seen.

Contrasting soil texture (from top): loam, heavy clay. (Photos: Eleanor Handreck)

Table 2. Main soil textural grades

Soil response to kneading and ribbon formation	Soil texture
Cannot be moulded; single grains stick to fingers	Sand
Ribbon 6 mm	Loamy sand
Sand grains can be seen, heard or felt; ribbon 15–25 mm	Sandy loam
Feels spongy; may feel greasy if much organic matter is present; ribbon about 25 mm	Loam
Very smooth and silky; ribbon 25 mm	Silty clay loam
Sand grains can be felt; ribbon 25–40 mm	Sandy clay loam
Smooth to manipulate; ribbon 40–50 mm	Clay loam
Sand grains can be felt or heard; ribbon 50–75 mm	Sandy clay
Feels like plasticine and can be moulded into rods without fracture; ribbons 75 mm or more	Medium to heavy clay

It is to be hoped that the soil compaction causing this ponding is relieved before a topsoil blend is spread.

moistened soil in your hand, as described in the box opposite. Then repeat from Step 18 with each of the soil layers below the topsoil.

Some soil properties related to soil texture

Water percolates readily through sands, loamy sands and sandy loams (except those that are water-repellent). Salts are readily leached from these soils, so plants in these soils can be irrigated with water that is too salty for use on heavier (clay) soils. On the other hand, fertilisers applied to sands are also readily leached out. Compost and other slow-release fertilisers are very useful for supplying nutrients to plants in sandy soils.

Clay soils, other than those with an excellent structure, are generally difficult to dig as they can be sticky when wet and often set hard on drying. Unless they are deeply cracked, water penetration into many clays is slow. In fact some clays are virtually impervious to water if they are already wet or have been pugged (worked into a soft, plastic condition without air pockets). When wet, they make ideal sealing materials for earth-fill dams.

Loams are a mixed bag of soils. From a gardener's point of view, the best loams drain freely, yet hold plenty of water for plants. They are easy to dig and give good conditions for root growth. Silty loams often set very hard on drying. Crusts that act like prison walls for germinating seeds readily form on the surface of some clay loams. These soils can be improved.

Clay and humus

Clay and humus are the smallest particles of soils. Clay and humus particles are so small that 500 of the largest clay particles and 200 000 of the smallest will fit side-by-side on a line 1 mm long. Smallness means that the surface area of even a small amount of clay or humus can be huge. For example the particles in one cubic centimetre of the finest clay have a total surface area of about 650 m^2.

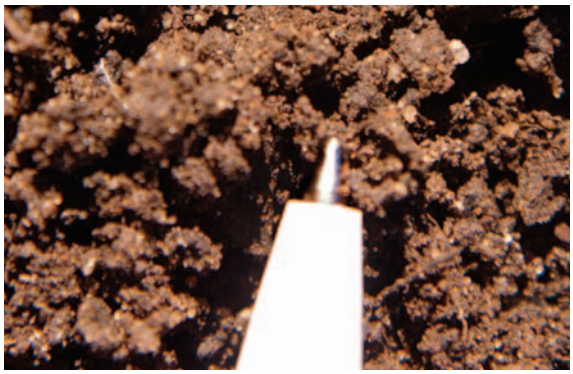
Clay and humus are vitally important because:

- they control the supply of many nutrients to plants
- they reduce the loss of plant nutrients from surface soils into water percolating through the soil
- they dominate the ability of a soil to maintain a stable pH
- they have a major effect on the physical properties of a soil, particularly its ability to hold and supply water and air and to provide a good environment for root growth.

Soil structure

Texture is an important soil property, but even more important is the way the particles that produce texture are grouped together. Soil structure is a term used to describe the way the particles of a soil are arranged together. Good structure is essential if plant growth is to be excellent. A soil has good structure if:

- the mineral particles and humus are grouped together into crumbs, or aggregates
- these aggregates are arranged together so that there are spaces, called pores, between them
- the particles that make up each aggregate are bound together firmly enough so that the aggregates do not break apart when rain falls on them or during normal digging
- the particles of each aggregate are still held together loosely enough so that small roots can penetrate into them to get water and nutrients
- the aggregates are generally quite small, ideally 0.2–3 mm across, rather than larger clods that are quite dense.



Aggregates are an essential part of good soil structure.

Aggregates are 'glued' together by organic matter, clay particles that are rich in calcium and secretions from roots and micro-organisms. The best way to improve the structure of a soil is to add organic matter to it. Many clay loams and clays also benefit from an addition of gypsum (which supplies calcium). Some sandy soils are improved through the addition of a modest amount of clay (see below).

Good things about good structure

Good structure allows water that falls on the soil to soak in quickly. It enables plant roots to grow easily through the soil. The roots are able to make contact with most of the water and nutrients present in the soil. Good structure also allows ample supplies of oxygen from the air to percolate down to roots. It prevents waterlogging (see p. 114) by allowing rapid drainage of excess water. Good structure reduces the effort needed to dig a soil compared with that needed for a soil with poor structure.

Poor structure

Soils with poor structure tend to have their particles joined together into dense sheets or large clumps. These soils may behave in one or more of the following ways:

- they will probably be difficult to dig
- they may be inclined to remain waterlogged for extended periods during the rainy season
- aggregates at their surface may collapse during rain or irrigation, with the

collapsed material forming a dense crust. Such a crust will greatly slow the rate at which water can get into the soil
- they may break into clods which give a very rough seed bed.

Improving the structure of sands

There is not enough clay present in sands to form aggregates, but they still have a structure produced by the loose packing of the grains of sand. But because water is only stored in the spaces between sand grains, and not within them as with aggregates, the total amount of water held for a given depth of sand is generally less than that held in the same depth of a loam (see Table 3 on p. 51). So is it sensible to add some clay to sands to increase their water-holding capacity? The answer is generally 'yes', especially if the sand is water-repellent. Adding clay is a cheap way of permanently overcoming water repellence.

The low water-holding capacity per unit of depth of sands has often been considered a problem because frequent application of water is needed to maintain shallow-rooted plants in them. But the real problem is that the wrong plants are being grown. There are plants that grow very well in deep sands without frequent watering. Here is the proof.

The deep sands of low rainfall areas of south-western Western Australia support a huge number of plant species through some of the harshest summer droughts in the world. These plants thrive in these deep sands because their seedlings rapidly produce extensive root systems that penetrate to as deep as 20 m. They therefore gain access to the water in a large volume of soil and in the water table whose surface may be 10–20 m below the surface. They do not have to rely on the small amount of water held in the uppermost 30 cm, which is all that is accessible to the shallow roots of many other plants.

Deep roots are essential to survival in the sand plains of south-west Western Australia.

So if the soil of your garden is a deep sand, the simplest way to have an excellent garden is to grow only those plants that have extensive and deeply penetrating root systems. You will choose plants that grow naturally on deep sands in areas of fairly low rainfall.

However, you might well choose to modify small areas of your sandy-soil garden if you

want to grow shallow-rooted plants such as fruit trees, vegetables and herbs.

You can convert the top 20 cm of a sand into a sandy loam or loam by adding 20–40 kg of crushed clay soil per square metre and a 10 cm layer of organic matter and **thoroughly** mixing them together, preferably with a rotary hoe.

Improving the structure of clay soils

Many, but not all, soils with high clay contents are difficult to manage in gardens. Difficult clay soils can be improved by:

- adding large amounts of organic matter
- adding a source of soluble calcium, such as gypsum or calcium nitrate, if testing shows that a benefit will be obtained
- (maybe) adding sand.

Improving clay soil structure with soluble calcium

If your soil shows the following signs of poor structure:

- is slippery and sticky when wet,
- tends to slump and get very muddy during rain,
- forms a crust on drying,
- allows only slow entry of rainwater,
- does not break into anything smaller than large clods during digging,

then it is likely that application of soluble calcium to it will improve its structure. (Use the test below to see whether your soil will benefit from an application of calcium.)

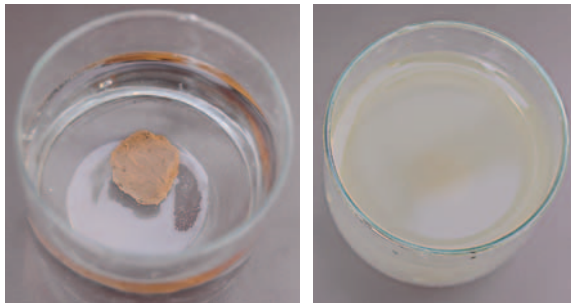
An excellent source of calcium.

Extra calcium can be supplied in two ways:

1. The simplest for gardeners to use is gypsum (calcium sulphate). Apply 1–2 kg per square metre. It may be left on the surface or dug in, whichever is easiest. Rain and irrigation will dissolve gypsum applied to the soil surface and move it down into the soil.
2. Improvement will be more rapid if you also add one dose of a more soluble source of calcium such as calcium nitrate or NUTRIsorb Ca9® (available from suppliers of specialist products for the turf industry) along with the gypsum. A soluble source of calcium is particularly useful when the amount of water available to leach the sodium displaced by calcium from the topsoil is limited. For calcium nitrate, apply 20–30 g/m^2 and water in thoroughly.

How to check for a need for extra calcium

Take a sample of the soil in the palm of one hand, add some rainwater or deionised water (not tap water, as the salts in it will give a false



Gypsum response test. Soil cube immediately after placing it in the water (left); 24 hours later (right). Cloudiness indicates a need for gypsum.

result), and knead the soil until all the lumps have been broken up. Squeeze some of the kneaded soil into a cube about 5 mm across. Drop this into a glass of the rainwater or deionised water.

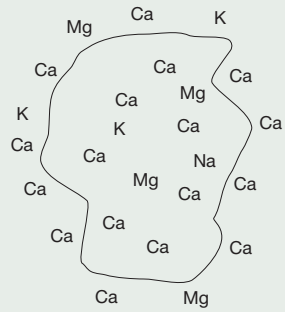
Watch what happens over the first hour, and then after 24 hours. Do not disturb the glass during the test. You will see one of the following:

- some aggregates remain unchanged, even after 24 hours
- others fall apart within the first hour, but the smaller aggregates so formed remain where they fall
- others, whether they fall apart or not, slowly disperse into the water, first forming

HOW CALCIUM WORKS

Cloudy water in the test just described indicates that the proportion of sodium ions relative to calcium and magnesium ions on the clay particles is too high (technically, the soil is said to be 'sodic'). The sodium ions prevent the particles from coming close to one another. They can be forced closer, or prevented from separating in the first place, if the concentration of any salt in the solution around them is increased. That is exactly what happens when a sodic soil is irrigated with salty water, including laundry effluent water when laundry powders are used (see p. 61). However, as soon as water of lower salinity, like rain, falls on the soil and dilutes or washes away some of the salts, the full effect of the sodicity soon shows. The only salts that give lasting improvement are calcium salts.

Gypsum is slightly soluble in water. The salinity so produced is the first step in improving a sodic soil. But the calcium of gypsum also has a more permanent beneficial effect on soil structure. Its calcium exchanges place with sodium on clay particle surfaces. This also allows the particles to move closer together and to remain there. The displaced sodium ions move away from the particle surfaces. With enough water, they are flushed away into the subsoil. One application of gypsum will continue to provide calcium for this process for many months to years.



Cations are held on the surfaces of clay and humus particles.

a ‘halo’ of clay particles around the aggregate. This halo then spreads to a general cloudiness throughout the water.

Extra calcium will not improve the structure of a soil whose aggregates remain unchanged or that fall apart without dispersion during testing.

Calcium will improve any soil that produces cloudiness during this test. The greater the cloudiness of the water, and the more rapidly it develops, the greater will be the benefit of adding extra calcium to the soil, and the higher the amount needed.

Improving clay soils with sand

You already know that clay soils have less sand in them than sands and loams, so you might conclude that just adding some sand to them will make them easier to manage. ‘It ain’t necessarily so!’ If you add only a small amount, say 10% by volume (about 15 L per square metre to treat the top 15 cm of the soil), you will almost certainly worsen the structure of a clay soil. The sand will simply clog the few spaces that there are in the clay.

Here are some guidelines for those who do want to improve a clay soil through the addition of sand.

It is only after you have added sand with a volume of 60–200% of that of the soil being treated that there will be a noticeable improvement in the structure and drainage of the soil. The more clay in the soil, the greater the volume of sand needed to gain improvement. The sand and soil must be thoroughly mixed together. This mixing must not be done when the clay soil is very wet. You will cause serious damage to whatever structure it has if you do this. Wait until at least three days after rain.

Improvement in structure will be greatest if you include plenty of organic matter (and gypsum if testing shows a need) in the top 15–20 cm of the new soil. Decomposition of this organic matter by micro-organisms will form humus that will bind the sand and clay into stable aggregates. Growth of plant roots will aid this process. It will take some years for the full benefits to be obtained.

This otherwise excellent Santa Ana couch lawn, which survives Adelaide summers with minimal irrigation, had a small patch that died off each summer. Digging showed the cause as the concreted stump of a clothes line that had been left *in situ* when the lawn had been established. The grass in this patch had access to a 15 cm deep reservoir of water instead of the more than 2 m (Table 27, p. 123) elsewhere.

ORGANIC MATTER AND SOILS

KEY POINTS

Organic matter is a vital component of all soils
Organic matter improves soil structure and water-holding capacity
Humus explained
How to make and use compost
A few problems to avoid

Organic matter is a vital part of all healthy soils. Its main beneficial effects are:

1. Improved soil structure, so that:
   - the soil holds more water for plants
   - water readily moves into the soil
   - waterlogging is less likely.
2. A major source of nutrients for plants.
3. Reduced leaching of plant nutrients from the soil.
4. To buffer the soil against rapid change in pH.
5. Biological control of disease-causing microbes through the decomposition of newly added organic materials. Adding organic matter is a powerful way to control plant root diseases without chemicals.
6. Hormonal effects on plants, especially to improve root development.

How organic matter improves soil structure and water-holding capacity

When you apply compost, cow manure, poultry litter or a green manure crop to a soil, there is a massive explosion in the population of microbes in it. These microbes (bacteria, fungi, etc.) produce sticky secretions and humus which bridge the gaps between mineral particles or groups of mineral particles and so bind them together into crumbs or aggregates.

Typically, no more than 30% of organic materials added to a soil remains after a year. The rest has been used as food by countless hordes of micro-organisms and has ended up as carbon dioxide, water and nutrient elements that have been released into the soil.

As the years roll by, less and less of the remaining organic matter is able to be used by micro-organisms. Some of it is protected by being sandwiched between clay particles. Much of it is humus. This is long-lived and is vital for the well-being of your soil and to future generations of plants that will grow in it. Humus is essential to good soil structure and the ability of your soil to provide air and water to the roots of your plants.

Tables 3 and 4 (pp. 51 and 52) give examples of the ability of organic matter to increase a soil's ability to hold water. Adding organic matter to a soil is a powerful way of maximising the retention of rain or irrigation water in the soil.

Humus

Humus is the more-or-less stable part of soil organic matter remaining from the decomposition of plant and animal remains. It is dark-coloured and consists of large organic molecules containing mainly carbon, hydrogen and oxygen. These molecules are stabilised by aluminium. They also contain considerable amounts of nitrogen, sulphur and phosphorus, and smaller amounts of other elements. Most humus is probably formed from lignin, the material that gives wood and plant stems their rigidity.

Increasing the organic matter content of your soil

The two simplest ways of increasing the organic matter content of your soil are by leaving all fallen sticks and leaves on the soil surface to rot down naturally, and by applying compost.

Compost

Compost is what is left of dead plants after they have been placed in bins or heaps and partly decomposed by microbes. All gardeners can produce some compost for themselves.

Incorporating large amounts of compost into the soil is essential when a new garden is being created. A 10 cm thick layer mixed into the top 20 cm of soil would not be too much. The need for later additions depends on how much natural recycling of organic matter is taking place. Where all leaves and twigs falling from shrubs and trees remain under them, no extra compost may be needed. But where leaves are removed, topdressing with compost every few years is desirable. Where the soil is used to grow vegetables, it is essential that compost be added to the soil at least annually.

Commercially produced compost

Commercially produced compost can be bought from garden centres and landscaping supply yards. These composts have been produced from the green organics that are now universally collected in our cities and towns for recycling. Compost that conforms with the provisions of the Australian Standard for Composts, Soil Conditioners and Mulches is guaranteed to be free of weed seeds, pathogens, toxicity and harmful levels of heavy metals, and to have minimal levels of contamination and nitrogen drawdown. The package will give information about its rate of use so that plants are not harmed by its salinity. Compost that does not indicate conformity with the Australian Standard may

Turning a green organics windrow at Jeffries Landscape Suppliers, Buckland Park, South Australia.

be OK, but it may not be. Note that some (non-Standard) composts produced from the manure of feedlot cattle have such high levels of zinc (700–1000 mg/kg) that their repeated use over some years can cause zinc toxicity to plants growing in acidic soils. Poultry manure products have much lower zinc concentrations.

Home-made compost

All you need to do is to drop the materials to be composted into a bin. You will have useable compost in six to nine months.

1. Buy a plastic compost bin.
2. Sit it on the soil (preferably), paving blocks or an area of concrete in a part of your garden that is easy to get to without getting your shoes dirty.
3. Lift the lid and tip your kitchen scraps, lawn clippings, weeds and moistened autumn leaves into it.
4. Continue until the bin is full. Occasionally lightly sprinkle garden lime onto the materials, but don't do this if you want acidic compost for putting around acid-loving plants, or if the pH of your soil is already at 6.5 or higher.
5. After about six months you will be able to remove compost from the base of the bin, either through the door, if your bin has one, or through the opening created by raising the bin vertically by 10–20 cm.
6. Larger families may need to use two bins. The contents of the first bin should have rotted down to compost by the time you have filled the second bin.
7. You can speed up the composting by adding earthworms to the materials. They will probably come in naturally if the bin sits on soil, but otherwise you can get some from a friend's compost bin or buy compost worms from a garden centre.

Because the materials in a compost bin do not get hot enough to kill pathogens and weed seeds, do not add diseased plants and any with viable seeds on them to these bins. Put these materials in the green organics recycling bin so that the heat generated

Two of the many types of domestic compost bins that are sold at hardware stores.

during commercial composting (60–70°C) will pasteurise them.

Other organic materials

Many different types of organic materials are available in garden centres and hardware stores. Here is comment on a couple of them.

Pelleted poultry manures have quite high concentrations of soluble nutrients, so do not use them at higher than the rates recommended on packages, which is usually not more than 300 g per square metre. You could repeat the application after a month or so if your plants need more feeding. The high phosphorus content of poultry manures means that you must not apply them to phosphorus-sensitive plants (see p. 26).

Most products labelled as **mushroom composts** are the spent composts removed from mushroom farms after a mushroom crop has been harvested. The material contains both the compost and the 'casing' onto which the mushroom spore was sprinkled. Mushroom composts themselves are usually of neutral pH, but casings are very alkaline, so spent mushroom composts are usually alkaline. Their high nutrient content often makes them very salty. Do not use such composts if your soil is acid and you want to keep it that way. Use them much more sparingly than you would use 'ordinary' composts.

Note the comments on p. 24 about the adverse effects of fertilisers, both organic and inorganic, on plants' drought tolerance.

Mulch or dig in?

There is no point trying to dig organic materials into the soil under trees and shrubs. You will damage too many roots. Spread the compost on the soil surface and top it with a coarse mulch (see p. 100). Microbes and earthworms will do the rest for you.

You can dig compost into the soil of a vegetable patch.

Organic gardeners might also make a surface application of compost between rows of vegetables part-way through a growing season.

Possible problems caused by organic matter

While adding organic materials to your soil is overwhelmingly beneficial to that soil and to your plants, there are a few problems that need to be avoided.

- Use of diseased plant materials can spread disease to your garden. That is why composts are the safest materials to use for providing extra organic matter to your soil.
- Some fresh plant materials contain natural chemicals that are toxic to the roots of young plants. Composting eliminates these toxins.
- Woody materials have very low concentrations of nitrogen. If you dig them into a soil, the microbes that decompose them will use soluble nitrogen in the soil and so decrease supply to your plants. The coarsest of these materials can be used as mulches, but the finest (e.g.

sawdust) need to be composted before use in the garden.

- Repeated heavy additions of organic materials to sandy soils will tend to make the soil water-repellent. This is less likely, but not impossible, with clay soils. Deal with water repellence as shown in Chapter 5.

Growing in the reservoir.

YOUR SOIL IS A RESERVOIR

KEY POINTS

Soils are reservoirs of water for plants

Deep roots = access to more water

Maximising water entry into your soil

Using organic matter to increase the amount of water held in your soil

Most of the water that flows from our taps and showers comes from a reservoir that stores rainwater. Reservoirs are mainly lakes that have been created by placing a wall across a stream or river. The other main type of reservoir is a natural underground store called an aquifer, from which water is pumped via a borehole. This water too was once rain that percolated down through the soil.

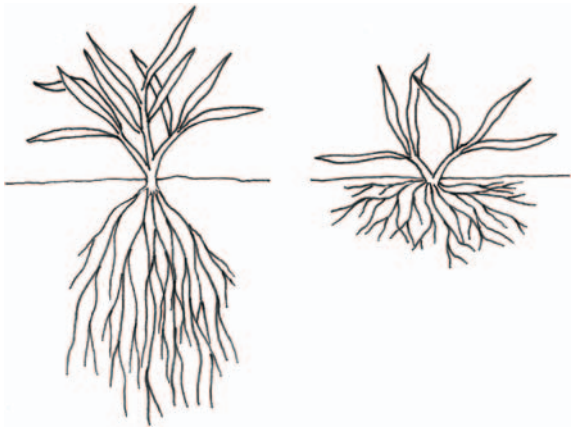
Some facts about reservoirs are:

- The larger the reservoir, the longer will it be able to supply water, if it starts off full.
- The faster the rate of removal of water, the shorter the time until it runs dry.
- The higher the rainfall in the catchment area of a surface reservoir, the faster will be its filling.

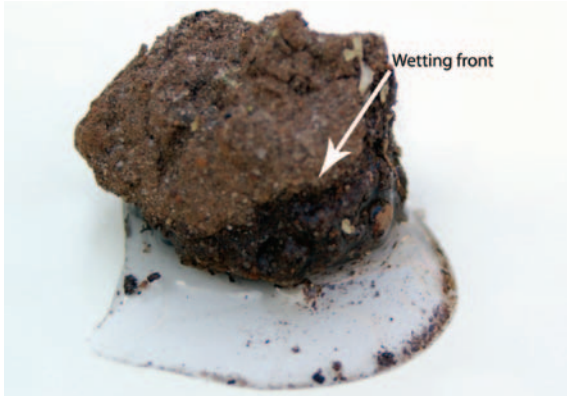
The soil of your garden is a reservoir that stores water for your plants. It is filled by prolonged rain or irrigation. It is emptied mainly by plants, but also by losing water through its leaky bottom and by evaporation from its surface. The length of time it can supply our plants depends on:

- **Its size.** Reservoir size increases as the depth of soil wetted by rain or irrigation water increases. But as far as our plants

Reservoirs hold water for our use.



The deeper roots penetrate into a moist soil, the larger is the reservoir of water that is available to the plant.



The tiny spaces (capillaries) between particles in this soil aggregate quickly attract water. The arrow indicates the border between dry and wetted soil.

are concerned, the effective maximum size of the reservoir is the volume of soil into which their roots grow. A plant whose roots penetrate one metre into moist soil has access to about double the amount of water contacted by a plant whose roots penetrate to only half a metre.

- **Type of soil.** Different soils have very different abilities to hold water (Table 3). Not only does the total amount of water held vary, so also does the availability of that water to plants. Adding organic matter to a soil usually increases its ability to hold water (Tables 3 and 4, pp. 51 and 52).
- **Rate of removal by plants.** Obviously, the greater the rate of removal, the shorter will be the time until the reservoir dries up.
- **Mulch quality.** Water evaporating from the soil surface is lost from the reach of our plants. This loss can be minimised by covering the soil surface with a blanket of an effective mulch (see Chapter 9).

How water is held in soil

If we turn a cup of water upside down, all the water runs out, pulled out by the force of gravity. The top part of a soil is a bit like an upturned cup; it doesn't have a leak-proof bottom to it. Why is it that all the water in it doesn't just run out into the deep subsoil? The answer is that soil particles and water usually like to stick together; water is attracted to the surfaces of soil particles and is held fairly firmly by them.

This attraction can be seen if you touch a small clod of dry soil to water sitting on a plate: the water is rapidly pulled – soaked – into the soil. Attraction can also be seen when we stand a pot of dry garden soil in a shallow tray of water. The surface of the soil will be wet within a few hours because the attraction between soil particles and water pulls water up against the downward pull of gravity.

The total 'amount' of attraction per cubic metre of soil will be greatest for soils with the greatest total particle surface area. That means that clay soils, with their huge numbers

A wetting front moving down through dry soil.

of small particles and therefore large total particle surface area, have a greater total 'pull' on water than does the same amount of a sandy soil. Table 3 gives a rough idea of the amounts of water that can be held in soils of different textures.

Getting water into soils

It is absolutely essential that the rain or irrigation water that you do have produces the maximum benefit to your plants. That means that as much of it as possible must soak into your soil.

It is of course impossible for any soil to soak up all of the water in a deluge from a thunderstorm or a tropical downpour. Much of the water of light showers falling onto already very wet soil may not soak in.

The rate at which water soaks into soil – the infiltration rate of the soil – is usually highest for sands and least for heavy clay soils. The range can be from more than 100 mm (depth of water) per hour to less than 5 mm/hr. It could be less than 1 mm/hr for a heavily compacted clay soil. The optimum range is roughly 10–25 mm/hr.

Here is what happens when rain falls onto a soil. Some water enters the soil and fairly quickly flows down through any large holes, such as cracks, worm burrows and old root channels. Some of the water soaks out from these large holes into the surrounding soil. Other water slowly soaks down from the surface through smaller channels between the large holes.

Infiltration of water will be slow if there are few or no large holes. It will be especially slow if the aggregates of the soil surface fall apart and clog the channels.

How to increase the water infiltration rate of your soil

The rate of infiltration of water into a soil is increased as follows.

- Overcome crusting and prevent crust formation:
  - Protect the soil surface with mulch and ground cover plants.
  - Apply gypsum, if testing has shown it to be useful.
- Maintain good soil structure and improve poor structure:
  - Maintain or increase the organic matter content of your soil.
  - Prevent compaction of surface soil. That means avoiding, as much as possible, walking over wet soils. Such walking compacts the soil by collapsing

Ground cover plants such as this *Portulaca intraterranea* protect the soil, and also look attractive. (Photo: Eleanor Handreck)

Layers of different types of soil are often created during building and landscaping operations. Some can reduce movement of water into the soil.

pores between aggregates, decreases the porosity of a soil, and so reduces the infiltration rate. Compaction will be greatest during the first couple of days after rain or irrigation, and becomes less as the soil dries out.

  - Don't dig the soil when it is very wet. Wait for one to two days after rain or irrigation. Digging is easiest after the soil has drained for this time.

- Mix any layers of soil of different texture: Dig 30 cm deep holes into the soil at a number of places around your garden, or at least where water ponds during prolonged rain. Look closely for any of the following:
  - A layer of heavy clay that has been compacted by construction machinery or soil that has been stuck together with cement residues. Such a layer may totally stop root growth through it. The depth of the reservoir available to your plants will then be only that of the surface soil above the compacted layer. If the garden is new, you should consider starting again after you have broken up the whole of the compacted layer of soil. For a longer-established area, you need to punch a large number of holes through the compacted soil with a crowbar or auger.
  - A layer of coarse sand underlying soil of finer texture, which will act as an anti-drainage layer. This is because the suction exerted on water by the fine soil is greater than that exerted by the coarse sand. Water will not pass into this coarse sand until the soil above it is saturated. The soil above it will remain wet enough after drainage into the sand has stopped to cause damage to plants that need good drainage. Buried layers of coarse sand are usually not natural, but have been put there by uncaring builders and left there by incompetent

landscapers. Mixing the coarse layer into the soil above and below it will overcome the problems.

- Reduce slope through terracing:
  - The steeper a slope, the more likely is it that rain will run off before it can soak into the soil. Any slope that is steeper than about 5% (1 m drop in 20 m horizontal distance) should be terraced. Remove the topsoil before terracing and spread it back over the top of the subsoil behind the retaining walls.
- Overcome water repellence in sandy soils.

Water-repellent (non-wetting) soils

Many very sandy soils are naturally somewhat water-repellent. Other sandy soils can become water-repellent following the addition of large amounts of organic matter. Water can sit in pools on the surface of the dry soil or channel down in only a few places. Difficulty in wetting is caused by the presence of waxy materials on the surfaces of sand particles. These waxy materials are produced mainly by fungi as they decompose organic matter.

If a few drops of water take longer than about a minute to soak into soil that has been thoroughly dried in the sun, the soil should be treated to overcome its water repellence.

Improving wettability

There are two ways of improving the wettability of non-wetting soils.

1. Add clay: Non-wetting of sandy soils can usually be permanently cured by increasing their clay content to above about 8%. The amount of clay to be added depends on the depth of sand to be treated. For 10 cm depth, add 10–20 kg clay soil to each square metre. For 20 cm depth, add 30–40 kg/m^2. Mix sand and clay very thoroughly, preferably with a rotary hoe. This action should eliminate the need to use wetting agents.
2. Use wetting agents: A wetting agent is really just a special type of detergent that is only slowly biodegraded and is not toxic to plants at the recommended rate of use. The wetting agent allows water to spread more easily across the surfaces of particles in a soil, in much the same way that soap or detergent allows water to spread over and stick to a greasy plate. All wetting agents are eventually biodegraded. After three to six months, more may need to be applied.

Despite what advertisements say, wetting agents are usually needed only on sandy soils. They are unlikely to improve the wetting of clay soils, unless these have been made water-repellent through very heavy applications of organic materials.

How to apply wetting agents to sandy soils

1. Use a fork to make small holes in the soil.

2. Apply wetting agent as per the label, but typically at 5 mL of concentrated wetting agent per square metre. You must dilute the concentrated wetting agent so that the 5 mL is carried in about 2 L of water. Thus, 25 mL of wetting agent in 10 L of water will treat 5 m^2 of soil. Use a watering can. Alternatively, apply a granular form of wetting agent at the recommended rate.
3. Encourage penetration of the solution by further forking, if necessary.
4. Then apply water at a low rate (5–10 mm per hour) so that water can penetrate deeply into the soil. If you cannot use sprinklers, apply the wetting agent (either liquid or solid) during rain or just before it looks like raining.

Because all effective wetting agents are toxic to plants if applied at higher rates than recommended, do not use gadgets that apply wetting agents every time you water.

Water in soils

If we are thirsty, we can drink a glass of water, right to the very bottom. Plants are not so fortunate. They cannot completely drain the reservoir of their soil, even if they are short of water. This section gives information about the size of the reservoir in different soils and the proportion of that water that can be used by plants.

Let us suppose that steady rain has delivered 100 mm of rain to your soil. That means that, if the water were all sitting on the surface, it would cover the soil to a depth of exactly 100 mm. We will assume that the soil was fairly dry before the rain, and that the plants growing in it would have needed watering within a couple of days.

Let us further suppose that all of the rain has soaked into the soil. While some has gone a long way down worm burrows, the average depth that is now moist will be something like 0.7 m for a clay and up to 1.4 m for a sand. It will have taken no more than a few hours for the water to finish draining down through the sand. Drainage down into a clay soil would have taken many days.

Field capacity

When the main drainage of water down into a soil has finished, that soil (or rather, that part of it that is now moist) is said to be at 'field capacity'. The reservoir is full to that depth.

The soil is able to hold approximately this amount of water for long periods if evaporation from its surface, and transpiration by plants, is prevented. In a soil at field capacity, water has drained from the largest pores, but all small and many medium-sized pores are filled with water. You can get an idea of what happens from the way that cooking water drains from the larger spaces between peas but some water is left in the smaller spaces where the peas touch one another.

It follows from this that a given depth of a soil with many small and few large pores (clay) will hold more water than will the same depth of a soil with few small and many large pores (sand), as shown in Table 3.

Table 3. Approximate amounts of water held in soils of different textures

Soil texture	Number of mm of water per cm depth of soil		
	Needed to wet the soil to field capacity	Available water*	Remaining at the permanent wilting point*
Sand	0.9	0.7	0.2
Loamy sand	1.4	1.0	0.4
Sandy loam	2.3	1.4	0.9
Sandy loam plus organic matter	2.9	1.9	1.0
Loam	3.4	2.2	1.0
Clay loam	3.0	1.4	1.6
Clay	3.8	1.4	2.4
Well-structured clay	5.0	2.0	3.0

* See the box below for a discussion of what these terms mean.

Enlarging the reservoir: how to increase the water-supplying ability of your soil

The most effective way of increasing the ability of your soil to supply water is to improve its structure (see above and Chapter 3). In particular, water must move quickly into the topsoil and there must be no barriers, such as a compacted layer, to water penetration into the subsoil. Organic matter is a key to excellent structure and deep water penetration. The combination of deep water penetration and plants that have the ability to send their roots deeply into the soil (see p. 18) is **the** most powerful way you have of maximising the size of the reservoir in your soil. Why waste all that lovely water by growing shallow-rooted plants?

There are many products that claim variously to save water, reduce water use, decrease watering frequency and so on. These claims are rarely supported by the results of independent testing. They often appear to be little more than marketing hype. The information provided in this book about how soils store water and how plants use water will

AVAILABLE WATER AND PERMANENT WILTING POINT

In Chapter 2 it was stated that when drought-sensitive plants wilt permanently, the soil in which they are growing is said to be at the 'permanent wilting point'. There is still some water left in the soil, but these plants cannot use it. The difference between the amount of water held in the soil at field capacity and at the permanent wilting point is the amount of water that these plants can use. This amount is referred to as the 'available water' content of the soil. Table 3 shows that loams and some well-structured clays hold the largest amounts of available water. Note how adding organic matter to a sandy loam, or improving the structure of a clay, increases the amount of available water that can be held.

In contrast to this response by drought-sensitive plants, drought-tolerant plants are able to extract some of the water that remains in a soil at permanent wilting point. The amount of water available to them is therefore higher than the available water contents listed in Table 3, but not as high as the total amount held at field capacity.

Table 4. Effect of decayed manure on the available water content of sandy soils

(From: Bouyoucos, GJ (1939). Effect of organic matter on the water-holding capacity and the wilting point of mineral soils. *Soil Science* **47**, 377–383)

Manure addition rate (cm depth mixed into top 20 cm of soil)	Sand (mm available water per cm depth of soil)	Sandy loam (mm available water per cm depth of soil)
0	1.2	1.6
5	1.7	2.0
10	1.9	2.2

enable you to assess these claims of large water savings.

Effect of organic matter on available water

Table 3 contains one example of the ability of organic matter to increase the available water content of a soil. Table 4 gives more examples. You can see that modest additions of organic matter increased the available water content of these light-textured soils by about 50%.

How useful are water crystals?

Water crystals are synthetic plastic materials that absorb many times their weight of water. Most of those currently on the market are cross-linked acrylamide/acrylic acid co-polymers with ammonium and/or potassium. Water crystals are sold for use in potting mixes and soils as a means of increasing water supply to plants. Here are some facts.

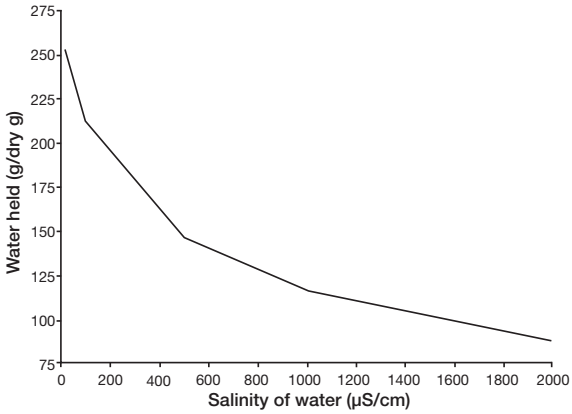
Effect of salinity

The amount of water these products absorb depends on the salinity of that water. It can range from about 300 grams per gram (g/g) of dry crystals for very pure water to only a fraction of this at high salinity. The graph gives an example for a product that is currently on the market.

The maximum amount of water held when water crystals are incorporated into soils is usually rather less than 100 g/g, because of the combined effects of salts, including fertilisers, and physical constraints on the swelling of the crystals in the soil. Research results for currently available products report amounts of about 50 g/g. Repeated cycles of wetting and drying gradually reduce the amount of water held by the crystals to zero after some years.

Availability to plants of the water held

Not all the water held by water crystals can be used by plants. Theoretically they should be



The amount of water held by water crystals decreases markedly as salinity increases.

One quarter of a teaspoon of water crystals before and after absorbing deionised water.

able to use 95% of it, but research results suggest that it could be no more than half the total held by the crystals, or as little as 25 g/g.

Despite these limitations, there is solid research and practical evidence that the water crystals currently available are useful in two ways in garden soils:

1. When planting trees and shrubs, survival rate and early growth will often be improved when you include a slurry of water crystals in the planting hole (see p. 110 for details).
2. If your soil is very sandy, including water crystals will allow the sand to hold more water and so extend the time until the plants must receive water again. Research results show that maximum benefit is obtained when the addition rate is in the range 100–300 g (dry) crystals per square metre, incorporated into the top 20 cm of soil.

Water crystals, and indeed any other means of increasing the water-holding capacity of a soil, do not reduce the amount of water used by your plants. In fact, your plants will use more water if the amendment allows them to grow bigger.

COMPARISON OF SEVERAL WATER-HOLDING MATERIALS

The data in Table 4 show that mixing a 10 cm layer of manure into the top 20 cm of a sandy loam soil increased its available water content by 0.6 mm/cm (2.2 – 1.6). Further additions are likely to be needed to maintain this effect over the years.

Coir fibre dust (e.g. Cocopeat) holds about 0.6 kg plant-available water per litre of expanded material. A 10% by volume addition to the top 20 cm of one square metre of a sandy loam will require 20 L of the coir. This amount will hold about 12 kg (= L) of available water (= 12 mm depth of water if it were spread over 1 m^2). This addition will therefore increase the available water content of the sand by 12 ÷ 20 = 0.6 mm/cm depth of soil. The coir will gradually decompose over several years, so the amount of extra water held will gradually decline.

What is the effect of mixing 100 g (dry)/m^2 water crystals into the top 20 cm to the same sandy loam? If we assume that the crystals hold 40 g plant-available water/dry g, the total amount of plant-available water held will be 100 × 40 = 4000 g/m^2. This is 4 L of water/m^2, which is equivalent to a depth of 4 mm water. This is 4 ÷ 20 = 0.2 mm water/cm depth of soil. It would be necessary to treble the addition rate (to about 300 g/m^2) to achieve a similar increase in available water supply to that given by coir or compost incorporated at the rates listed above.

Readers are left to decide which option will be best for their situation.

Ultimate salinity.

WATER QUALITY

KEY POINTS

How to check the quality of your water supply
Interpreting salinity readings
Easy interpretation of water analysis information
Minimising the effects of salinity on plants and soils
Greywater: all the facts
How to divert and use greywater without problems

Most water has various things dissolved in it. Even rainwater direct from the sky has a low concentration of salts from sea spray (common salt), lightning (nitrates), pollution and dust. This rain will pick up more salts (from bird droppings and leaves) as it flows from roof to tank. When rain flows over and through soils to reach streams and reservoirs, it dissolves more salts from the soils. In dry areas, more salts can enter streams from saline springs and seepage from irrigated crops. Greywater has extra salts from detergents. Low concentrations of salts in water do not harm our plants and soils, but as salt concentration increases, the possibility of harm being done also increases.

The simplest way of describing the salts in waters is by listing their separate parts – called ions. The important ions in water supplies are sodium and chloride (as in common salt), calcium, magnesium, bicarbonate, sulphate and phosphate.

How do I know if my water is salty?

The simplest way of finding the saltiness of your water is to ring your water supply authority or look up the information on their website. You will get a figure for the electrical conductivity (EC) of the water they supply to your area. The higher an EC reading, the saltier the water. EC readings internationally and for all Australian states except Western Australia are given in units called microSiemens per centimetre (µS/cm) or deciSiemens per metre (dS/m). One dS/m = 1000 µS/cm. Use Table 6 to interpret the figure. The units used in Western

IONS

The world is composed of chemical elements. We normally see only a few of these elements by themselves. These few include carbon (diamonds, graphite), sulphur (dusting sulphur), iron, zinc and aluminium. More often we see elements in combinations that are called compounds. The first two columns of Table 5 list a few of the many compounds that are soluble in water. When these compounds are dissolved in water, their two 'halves' split apart to form two parts that are called ions. One part takes on a positive electrical charge. These are called cations (pronounced *'cat-eye-ons'*). The other part takes on a negative charge. These are called anions (*'an-eye-ons'*). Table 5 lists the ions formed by the compounds listed.

Diamonds – one form of carbon.

Ions are very important because:

- It is mainly as ions that plant nutrients are held in soils.
- It is mainly as ions that nutrients are taken up by plants.
- The physical properties of soils are greatly influenced by the types and proportions of the cations of calcium, magnesium and sodium that are present on particle surfaces.
- Whether a soil is acid or alkaline is determined by the concentration of hydrogen ions in it.
- When plants are damaged by salty water, the extent of damage depends on the concentrations and types of ions that are present.

Table 5. The ions of some common water-soluble compounds

Common name	Chemical name	Chemical formula	Cation	Anion
Baking soda	Sodium bicarbonate	$NaHCO_3$	Na^+	HCO_3^-
Epsom salts	Magnesium sulphate	$MgSO_4$	Mg^{2+}	SO_4^{2-}
Sulphate of ammonia	Ammonium sulphate	$(NH_4)_2SO_4$	NH_4^+	SO_4^{2-}
Potassium nitrate	Potassium nitrate	KNO_3	K^+	NO_3^-
Common salt	Sodium chloride	$NaCl$	Na^+	Cl^-
Pool acid	Hydrochloric acid	HCl	H^+	Cl^-

Australia are milliSiemens per metre (mS/m). 1 dS/m = 100 mS/m. 1 mS/m = 10 µS/cm.

Those not on a municipal supply should have the EC of their water determined by a laboratory. A hydroponics shop might even do it for nothing.

An EC number tells you how salty your water is but it does not tell you anything about the concentrations of the different ions present. Some ions are much more damaging to plants and soils than are others. The ions that cause the most damage are sodium, chloride,

Table 6. How to interpret EC readings

EC range (µS/cm)*	Interpretation
0–500	Very low to low salinity, suitable for all plants. Municipal water supplies in Tasmania, southern Victoria, coastal NSW, SE Queensland, far north Queensland and the Top End are all in this category.
500–750	Sensitive plants, including ferns and fuchsias, and the seedlings of plants from high-rainfall areas, show burn around the edges of leaves and leaf drop if they are repeatedly misted with water of this quality. Application to the soil or potting mix should cause few problems other than tip damage to plants with long narrow leaves. Some greywaters from laundries that use powder detergents have salinities in this range.
750–3000	Increasing numbers of species show reduced growth, burning of leaves and even death as EC rises through this range. Some greywaters from laundries that use powder detergents have salinities towards the upper end of this range.
>3000	Unsuitable for irrigation except for highly tolerant plants being grown in sandy soils with excellent drainage. The water in swimming pools can have salinities in the range 3000 to 9000 µS/cm, with those in pools having salt-chlorinators being the highest. Sodium levels are very high. These waters must **never** be run onto gardens.

* Western Australian readers need to multiply an EC number produced in their state by 10 to compare it with the numbers in this table.

boron and bicarbonate. If your water has an EC above 500 µS/cm, you should find out more about it. Ask your water supplier or have your water tested for sodium, calcium, magnesium, SAR (see Table 7), chloride, boron and total alkalinity. Use Table 7 to interpret the information.

Modestly priced salinity meters are available from hydroponics shops.

How salts damage plants

Relative to low-salinity water, salty water slows seed germination, stunts growth and retards flowering. Salty water damages plants in several ways.

Damage to plants by increased soil salinity

Repeated addition of salty water to a soil gradually increases the concentration of salts

Some swimming pool test kits are able to measure the total alkalinity of water.

Table 7. How to interpret analytical results for water supplies

Ion	Interpretation
Sodium	
<70 mg/L	No problems. If >70 mg/L, increasing damage when applied to the leaves of sensitive plants.
>210 mg/L	Not suitable for watering sensitive plants. Many laundry powder detergents produce greywaters that have sodium concentrations in the range 200–700 mg/L.
Chloride	
<100 mg/L	No problems. If >100 mg/L, increasing damage when applied to the leaves of sensitive plants.
>355 mg/L	Not suitable for watering sensitive plants.
SAR*	
<6	No problems.
>9	Increasing problems for cracking clay soils.
>16	Increasing problems for non-cracking clay soils.
Boron	
<0.5 mg/L	No problems for most plants.
0.5–3 mg/L	Increasing numbers of plants show toxicity symptoms. Greywaters from laundries that use detergents that contain boron may fit here.
>3	Unsuitable for watering.
Total alkalinity#	
<100 mg/L	Generally no problems. The municipal water supplies of all major coastal Australian population centres have total alkalinity concentrations below 100 mg/L.
100–150 mg/L	May raise the pH of soils and potting mixes, but use of acidifying fertilisers can counter this. Greywater (wash plus rinse) from laundries that use liquid detergents have total alkalinities in the range 20–150 mg/L (on top of the alkalinity of the water itself).
>150 mg/L	Will raise the pH of soils and potting mixes. Grow only lime-tolerant plants. Alternatively, acidify the water with sulphuric acid; you will need professional help. Many bore waters and inland surface waters have total alkalinities above 150 mg/L. Greywater from laundries (wash plus rinse) that use powder detergents have total alkalinities in the range 40–1150 mg/L (on top of the alkalinity of the water itself).

*SAR = sodium adsorption ratio. It takes into account the concentration of sodium in relation to calcium and magnesium. See the section on damage to soils, below. If your water has a high SAR you should seek professional help for using it successfully.
Expressed as mg/L calcium carbonate equivalent.

in the water in the soil. These salts reduce the amount of water that plants can get from a soil, and also cause the plants to divert energy from growth to water uptake. If you have to apply salty water to your plants, you need to apply enough so that salts are leached down through the soil below the plant's roots.

The book *Grow What Where* (see Appendix 1) contains an extensive listing of Australian native plants of known high tolerance to salinity.

Damage to soil by sodium

The sodium of salty water damages the structure of clay soils. What happens is that sodium gradually displaces calcium and magnesium from the surfaces of particles in the soil, so creating a 'sodic' (high-sodium) soil. As long as the irrigation water remains saline, the aggregates in the soil can remain intact, but if salinity falls (as during rain) the aggregates fall apart. Particles 'float off' or disperse into the soil water. They can then form a crust on the soil surface. This will

drastically reduce the rate of infiltration of water into the soil.

As rainwater penetrates further into a sodic soil, it continues to cause aggregates to fall apart within the soil. Roots are less able to push their way through the soil. They are therefore less able to reach water and plant nutrients. The damage caused by sodium is lessened as the concentrations of calcium and magnesium in the water increase, because then the sodium is less likely to remain on soil particle surfaces. Put another way, 'hard' salty waters (those that reduce lathering of soap, and have a low SAR) are less damaging than 'soft' salty waters, such as those that have passed through water softeners. Greywaters from laundries can have extremely high concentrations of sodium (see Table 7).

Direct damage to plants

The chloride and sodium ions of salty waters accumulate at the outer edges and tips of the oldest leaves, where they kill cells. We see this

The lower leaves of this tree were killed through repeated sprinkling with water of about 1000 µS/cm salinity.

The tips and margins of these pansy leaves are being killed by boron toxicity.

as a browning and burning of leaf edges and tips and death of whole leaves. Leaf area is reduced; there is less green plant to capture sunlight so plant growth slows. Because chloride and sodium are taken up faster through leaves than through roots, salty water containing them damages plants most rapidly when it repeatedly bathes their leaves, as during overhead sprinkling.

The nutrient element boron is present in high enough concentrations in a few water supplies (mostly from bores) to damage sensitive plants. Violas, pansies and kiwifruit vines are especially sensitive: they are damaged by water with as little as 0.5 mg per litre of boron (see below for comment about greywaters).

Damage by alkalinity

High concentrations of bicarbonate in irrigation water will steadily raise soil pH, eventually to a level that will interfere with the supply of trace elements to plants that need acid soil. If the total alkalinity of your

water is above about 150 mg/L, you should grow only those plants that tolerate alkaline soils (see *Grow What Where* for a list of Australian native plants that would be suitable). Plants from alkaline soils elsewhere in the world (the soils of many desert areas are alkaline) could also be grown.

Waters with total alkalinities above about 100 mg/L will steadily raise the pH of potting mixes. You can counter total alkalinities of up to perhaps 150 mg/L through the use of acidifying fertilisers (those whose nitrogen is supplied mainly by ammonium and urea), but water with higher total alkalinity is unsuitable for use on potted plants.

Greywaters from laundries can have extremely high total alkalinities (see Table 7). If you do not want your soil to become alkaline, use liquid laundry detergents (see www.lanfaxlabs.com.au/laundry.htm). If you have to use water with a total alkalinity above 100 mg/L, every three to six months you should check the pH of the soil to which it has been applied. Apply sulphur if the pH is too high. Applications to reduce pH by one unit range from about 25 g/m^2 for sands to about 100 g/m^2 for clay soils.

Note also that some herbicides are inactivated when solutions of them are made up with alkaline water.

Minimising damage by salty water

- Keep the water off leaves. Misting with salty water is particularly damaging. Use drippers.
- Reduce evaporation from the soil through mulching. This will reduce total water use and therefore the total amount of salt added to the soil.
- Counter soil damage by sodium by applying gypsum, if testing shows that it will be beneficial.
- Do not let the soil dry out, as this will cause the concentration of salts in the remaining water to become very high. This effect is greatest in sandy soils.
- Leach excess salts from the soil. Leaching is easiest when soil structure is good. If possible, each time you apply saline water add 10–20% more water than is needed to fill the soil reservoir (Table 3).
- When using salty water on potted plants, you should add enough water each time to allow 5–10% to drain from the pots.
- Do not water plants with salty water that has passed through a water softener. These remove calcium and magnesium from the water and replace them with sodium.

Using greywater

The term 'greywater' is used to describe the waters that flow from our showers, washbasins and laundries. All state governments now allow greywater to be used on gardens, subject to various conditions. Water restrictions have forced many gardeners to recycle greywater to their gardens. For this activity to be free from problems, there are a few essentials that must be observed.

Greywater from the shower, bath and bathroom basin contains small amounts of soap, shampoo, conditioner, skin cells, urine and perspiration. The concentrations of these are low and they are mostly readily degraded

by soil microbes. This type of greywater can be used on any plants that tolerate the salinity of the incoming water used to create it. Because bathroom greywater quickly becomes smelly, it should be applied to the garden within a few hours of its production. Bathroom greywater that contains hair dyes, bleach and disinfectants should not be used in the garden.

Greywater from the laundry has the potential to cause serious problems. Many laundry detergent powders consist largely of various fillers, mainly sodium salts such as sodium sulphate and sodium bicarbonate, with only about 15–20% detergent. Laundry greywater can contain very high concentrations of sodium and phosphorus and can be very alkaline. If you do want to use greywater from your laundry in your garden, you **MUST** take note of the following if you are to avoid creating serious problems for your soil and plants. But when you use a non-polluting laundry detergent (see Table 8), you can use both the wash and rinse water on your garden. If you use a detergent that gives slightly higher concentrations of sodium and alkalinity than do these non-polluting detergents, you could let the wash water run to the sewer and the rinse water to the garden.

Sodium

Laundry detergent powders all have much higher concentrations of sodium than do the liquid detergents. Lanfax Laboratories of Armidale, New South Wales have published the results of analysis of effluent (wash plus rinse) produced from over 100 laundry detergent powders (see www.lanfaxlabs.com.au). Sodium concentrations in effluent ranged from about 710 mg/L to about 35 mg/L.

The concentrations in effluents produced from liquid laundry detergents ranged from about 130 mg/L to less than 2 mg/L.

You already know that sodium added to a soil displaces calcium and magnesium from clay particles. With addition of enough sodium, the soil will become sodic. So if you repeatedly apply greywater containing high concentrations of sodium to your soil, you will inevitably cause the soil to become sodic. The high concentration of salts in the greywater will at first mask the adverse effects of this sodicity, so lulling you into a false sense of security. But as soon as the salts are diluted with the next rain, all the bad effects of sodicity – slow water infiltration, damaged soil structure, surface crusting – will show up. The only way back from this mess is to apply a source of calcium (gypsum or a soluble calcium product, see p. 36) and use rain or considerable amounts of extra irrigation water to leach the sodium out of the topsoil. It is far more sensible to prevent this damage in the first place by using a laundry detergent that has a low sodium content but still gives you effective laundry performance. There are now many products to choose from.

Phosphorus

The phosphorus in laundry detergents is present as phosphates that help remove dirt from clothes. *Choice* magazine (see issues of June 2005, April 2007) has shown that laundry detergents that do not contain phosphorus generally do not clean heavily soiled clothes as well as do those that contain

Even native plants that are generally tolerant of phosphorus can be damaged by high additions of phosphorus. Shown here are leaves (left upper surface; right lower surface) from young trees of *Corymbia maculata* (Spotted Gum), *C. citriodora* (Lemon Scented Gum), *Eucalyptus leucoxylon rosea* (SA Blue Gum), *Angophora costata* (Smooth-barked Apple) and *Lophostemon confertus* (Tristania). The purple spotting and pustules are the result of severe phosphorus toxicity. The trees had been continually watered with high-phosphorus (14 mg/L) greywater. Powder laundry detergents with the highest phosphorus contents produce greywaters (wash plus rinse) with phosphorus concentrations in the range 20–80 mg/L!

phosphorus. However, if you want to use laundry greywater on your garden, you need to choose between having 'very clean' clothes (and potentially damaged soil and polluted groundwater) and slightly less clean clothes (and not polluting your environment with excessive phosphorus). You will probably only see the difference in white clothes.

The concentrations of phosphorus in the effluent waters reported at www.lanfaxlabs.com.au ranged from 80 mg/L to zero. Products that contained the lowest concentrations of sodium had no or very little phosphorus (Table 8). For those products with the highest concentrations of phosphorus, the total amount in a typical wash (wash plus rinse) was 6–8 grams. If you apply this high-phosphorus greywater to a soil that has an inadequate supply of phosphorus for the plants being grown, you will see that your plants put on luxuriant growth. But don't be fooled. Repeated additions of this greywater will soon start to produce problems. The 75 L of water from one wash would typically be applied to about 25 m^2 of garden (so giving an application of 3 mm of water). Weekly application to the same area for a whole summer would deliver over 5 g phosphorus/m^2. This is several times the annual amount of phosphorus removed in clippings from a domestic lawn and dozens of times more than is needed by ornamental trees and shrubs.

Application of these huge amounts of phosphorus to a garden soil will soon start to cause problems, including greater attack by mildews and insects on the lush plants, and interference with the use of trace elements by plants. Drought-tolerant plants will use much more water (see p. 24). With repeated applications, your plants may not be able to extract enough trace elements from the soil. If this type of greywater is applied to plants that are sensitive to

Table 8. Sodium, phosphorus and alkalinity in laundry greywaters (wash plus rinse for top-loading machines and 150 L wash cycle volume) for some laundry detergents with low soil-damaging potential

Laundry detergent#	Sodium (mg/L)	Phosphorus (mg/L)	Alkalinity (mg/L calcium carbonate)
Powders			
Aware Environmental Concentrate	90	0	190
Planet Ark	80	0	170
Biozet Advanced Concentrate	70	2.8^	100
Amway SA8	25	0	40
Liquids			
Earth Choice Laundry Liquid	5	0	20
Savings	4	0	20
Home Brand	2	0	20
Eco-wash*	0.5	0	1

Note that manufacturers may from time to time change formulations.
^ Packages in supermarkets in late 2007 carry the label 'NP (no phosphorus)'.
* Lanfax Laboratories data from the producer Sage Horticultural.
Source: www.lanfaxlabs.com.au

phosphorus (see p. 26), within weeks you will see that they start to yellow and die. This effect of excessive phosphorus will show up first, and be most severe, on sandy soils.

If you do have to use a powder detergent that contains phosphorus, choose one that has a low concentration and use the greywater containing it only on those plants whose parts are to be harvested (fruit trees, vegetables, cut flowers, bedding plants). Applying only the rinse water to drought-tolerant plants growing in clay soils may be acceptable, but this greywater must never be applied to phosphorus-sensitive plants (p. 26).

Boron

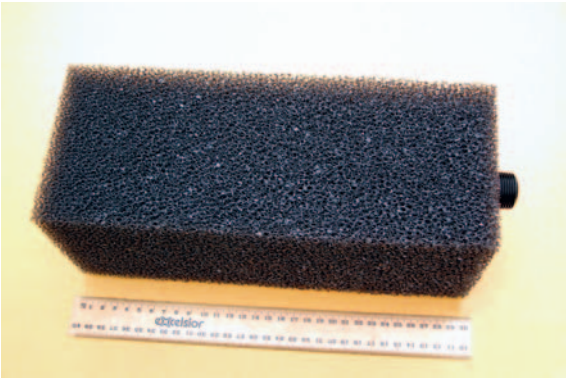
Do not use a detergent that contains boron (listed as 'perborate' on the detergent package), because it can build up to levels in your soil that are toxic to plants.

How to divert and use greywater

In all states, greywater can be diverted direct to your garden without the need for a permit, but you must apply it immediately or within 24 hours of producing it. The website www.health.nsw.gov.au gives a good summary of typical regulations. If you want to store greywater for longer than 24 hours, you must install an approved treatment system.

Where the laundry drain is easily accessible, this simple device allows the greywater to be either diverted to a surge tank or to run to the sewer.

Greywater diversion at its simplest. On sloping sites, gravity, rather than a pump, may be enough to distribute the water. If the outlet is at the base, you can completely drain the drum by slightly tilting it.



If you are distributing greywater via a (lilac-coloured) dripper line, you must install a pond pre-filter such as this to prevent fine lint from clogging drippers. Alternatively, a long 'sausage' of fine cloth over the end of the greywater inlet into the drum will remove lint, but it must not restrict flow from the washing machine.

One diversion method is to install 3-way diverters into the pipes from the laundry and bathroom and divert the water direct to the garden.

A better method is to divert the water into a surge tank from which it can flow or be pumped into greywater dripper lines. In fact, because washing machine pumps are damaged if flow from their greywater outlet is restricted in any way, it is essential that you let the washing machine pump the water into a surge tank. Make sure that fittings in lines do not restrict flow. Do not try to pump directly into dripper lines. The surge tank can be a recycled 200 L drum (see the Yellow Pages for drum recyclers) or one of the many manufactured systems. A 20 watt submersible pump as used for aquariums and small

Specially modified wheelie bins (shown in cutaway image) offer an economical way of catching and diverting laundry greywater. The small amount not removed by the pump is easily removed via a drainage plug. (Photo: Just Water Solutions)

Another type of greywater diversion system. The surge tank comes in 80 and 500 L capacities. (Photo: ESA Envirowater Pty Ltd)

hydroponics systems will pump water for short distances (up to perhaps 15 m through 12 mm hose) from a low-level surge tank.

You must observe the following precautions, especially in built-up areas.

The water must not:

- smell bad
- form ponds on the soil surface
- run onto neighbouring properties, into swimming pools and water features or into streams
- pollute the groundwater
- be applied to soils above an aquifer that is used as a source of drinking water
- be applied to the garden via sprinklers
- be applied around leafy vegetables that are to be eaten raw.

In addition:

- Pipes that carry greywater should be labelled to show that the water is not suitable for drinking.
- Do not apply greywater to soils within 1 m of boundary lines.
- Do not use greywater from the kitchen. Fats and oils in it can harm soils. However, you could collect and use non-fatty kitchen rinse water.

Apply greywater via slotted pipe buried in gravel-lined trenches in the soil or via dripper lines that are installed under mulch. The water must be filtered before going into dripper lines. Pond pre-filters may only need monthly cleaning, but cloth filters will probably need more frequent cleaning. Slotted pipe and dripper lines should be fitted with ends that can be opened to allow flushing. Have a regular maintenance program.

The plumbing for greywater distribution should be easily accessible in case blockages need to be removed. Flush the whole system every couple of months.

Any human pathogens in greywaters are rapidly killed by soil microbes, especially if there is plenty of organic matter in your soil.

Problems from greywater use will be least if you match the application rate to the infiltration rate of your soil. In particular, a low rate of application to a large area is preferable to a high rate to a small area. As a rough guide, if your laundry produces 400 L of greywater each week, in summer this needs to be applied to **at least** 15 m^2 in hot areas and to **at least** 30 m^2 in cooler areas. These

Example of the greywater treatment systems that must be used if you want to store greywater for later use. (Photo: Nubian Water Systems)

application rates are 26 and 14 mm/week, respectively. Application rates must be lower at cooler times of the year, down to nil when the soil is already at field capacity.

Over-application of greywater can be prevented through the use of the FullStop™ wetting front detector (see p. 80).

If you want to store greywater for longer than 24 hours, you **must** install an approved treatment system. These systems use filters, biological systems, chemicals or UV light to kill microbes in the water. Inevitably, these systems are expensive, but rebates are available from some state governments. There are now about a dozen systems to choose from. They must be installed by a specially licensed plumber (see www.greenplumbers.com.au). You must get approval from state and council authorities.

Compare systems on the basis of level of treatment you need, cost, size of tanks in relation to space available, service costs, maintenance needed, power consumption, number of moving parts that can break down, noise, use of toxic chemicals, odours produced and provision of warning of malfunction.

Water quality and potted plants

All the earlier comments about water quality apply to plants in pots, but there are a few extra details that need to be considered.

If your main method of watering is from below, for example by wick or from a capillary mat, occasionally water from above to leach out excess salts. How often 'occasionally' is depends on the salinity of the water used and on the evaporation rate, but it could be once a month for very salty water. When the water is pure, and fertiliser use not excessive, leaching might only be needed every couple of years.

When your water is salty, don't let the mix become too dry between waterings. Apart from the obvious effects of drought on plants, the water remaining in a dry mix can be lethal to plants because of its very high salt concentration.

In hot weather the combination of too much controlled-release fertiliser and a rapidly drying mix can quickly give plants a lethal dose of salinity.

DELIVERING WATER TO YOUR PLANTS

KEY POINTS

Make the most of rain

Five simple steps to delivering the right amount of water to your plants

Useful devices – controllers and sensors

How to water-proof a medium-sized garden

Not so long ago in most of Australia, it was possible to apply to gardens as much water as was needed to keep them lush. Sprinkler systems hooked to electronic controllers could be programmed to deliver water when needed, without restriction. Much of the drudgery of watering during months of rainless heat had been removed.

The combination of drought and rising population has radically changed all this. While watering by drippers is still allowed in many parts of the country, there are increasingly large areas where buckets filled with greywater are all that stand between drought-sensitive plants and death.

You are reading this book because you want a garden. You like to tend plants; you like the way plants keep your house cooler on hot days; you like the relaxation that you experience in your garden. You know that you are likely to live longer and suffer fewer illnesses if you garden than if you do not. But with restrictions on the use of water, how can you continue to garden? The good news is that you can, but you probably will need to make some changes to your garden and the way you manage it.

This chapter is about getting the most out of both the rain that you do receive and the water from the municipal supply that you are allowed to use on the garden.

Make the most of rain

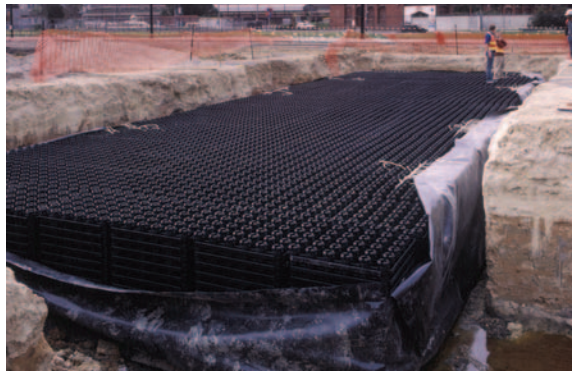
You must make sure that:

- as much as possible of the rain that falls onto your soil actually soaks into it (see the section on infiltration on p. 47).

- water that falls onto paths and driveways flows onto the garden. Pavers allow some of the water to penetrate between them into the soil below, where the roots of trees and shrubs can use it.
- as much as possible of the rain that falls on the roof of your house and sheds is diverted either directly to the garden or via storage tanks.

You should also seriously consider storing rainwater under your driveway and other non-garden outdoor areas such as patios. Two of many available systems are illustrated. A small solar-powered pump can be used to apply the stored water to the garden.

The University of South Australia porous paver system has a confined gravel bed for storing water that percolates through the large gaps between the pavers. With this system, it is possible to collect and store 8000 L of water under a double driveway.



The Rainstore[3] system uses a modular framework made from recycled plastic to support the pavement, so only a small proportion of the total storage space is taken up with support material. (Photo: Invisible Structures)

Benefits of rain

Gardeners often notice that after rain, their plants look much lusher and healthier than when the only water they get is via irrigation. Why does this happen? Several factors seem to contribute:

- Rain washes dust from leaves, so the green is not masked.
- Rain always gives more uniform watering than even the best irrigation system, so all plants get a drink.
- The air during and soon after rain has a higher humidity than at other times. Plant leaves remain turgid and more erect.
- Salt build-up in the soil will be diluted or removed, so enhancing plant uptake of water.
- Rain, particularly from thunderstorms, brings with it some extra nitrogen. This could 'green up' plants that are a little deficient in nitrogen.

Another effect of rain is that it washes some plant nutrients, especially potassium, from leaves. If the water then falls on soil below the

Potassium deficiency in *Dracaena fragrans*. (Photo: Keith Bodman)

plants, the nutrients are quickly recycled back into them. But if the water instead falls on a hard surface and is carried away, the plants in this area can eventually run short of one or more nutrients. Potassium deficiency symptoms are common on trees in hard-paved areas.

Diverting water from the roof

The rain that falls on the roofs of houses in urban Australia is mostly diverted via gutters and spouting to the gutter beside the road pavement at the front of the house (the so-called street water table). A small amount is collected in rainwater tanks, with the overflow going to the street. With increasingly dense urban housing, the volume of water from a modest rainfall event can be enough to overload the whole stormwater system and cause flooding of lowland areas.

In this driest inhabited continent, this is the height of lunacy. A bit of this stormwater is caught in wetlands from where it can be pumped underground for later use in parks,

Small water features give tranquillity to a garden. They can be filled by diverting rainwater from a small roof.

nurseries and racecourses. No doubt more of this stormwater will be collected and used in the future, but it makes sense if more of it is used where it falls.

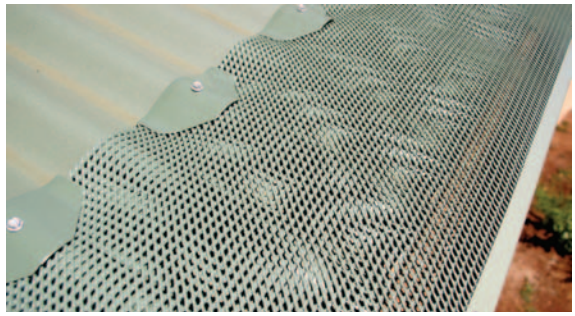
Here is how you can get the most out of 'your' rain:

- Install the largest rainwater tank or tanks that you can fit in. For an average house 5000 L is a minimum, with at least 20 000 L desirable for larger blocks. The water you collect will cost you more than does the water from your supply authority, but it is still a bargain if that authority has banned or severely restricted the use of its water on your garden. Your state government or local council probably offers a subsidy for new tank installations. (Relative costs – municipal water: about $1.25 per kilolitre (kL); tank water: about $4 per kL if the tank lasts 20 years and you collect and use about twice the capacity of

Even the smallest city garden can have a rainwater tank. Note the first flush diverter on the left.

the tank in a year; 'spring' water purchased in 600 mL one-use plastic bottles: about $4300 per kL at convenience stores; imported bottled water in upmarket restaurants: $8900 to $17 000 per kL.)

- For water of the highest quality and for minimal hassles with blockages, install gutter guards, gutter screens and a first-flush diverter between roof and tank. The first-flush diverter can also double as a means of preventing contamination of the tank when you clean the gutters. Screens must be regularly inspected and cleaned.
- Reduce leaf drop into gutters by removing tree branches that overhang the roof.
- Mosquitoes can be stopped from breeding in the tank by having screens over inlets and outlets and/or by regularly (after each overflow and weekly during summer) applying domestic kerosene to the water at 1 teaspoon per tank. Do not use power kerosene as it will taint the water.
- Have the tank base as high as is possible. Of course the roof water must still run into the tank, but the higher the base the



Essential parts of a rainwater collection system (from top): gutter guards, leaf screen, first flush diverter.

greater the pressure you will have for gravity feeding the water to your garden or to taps inside the house.

- Install the tap on the tank in such a way that it is easy to connect it to a dripper system that will water your most valuable plants. You may need to install a pump so that there is enough pressure for the drippers to function effectively. For a typical dripper line, you need only install a small pressure pump that is capable of supplying about 10 litres of water per minute.
- Arrange the overflow outlet of the tank so that overflow water can flow either to the street or be applied to your garden. A main reason why governments have required stormwater to be diverted to the street is concern that the water may otherwise cause problems by flooding neighbouring properties. You can therefore only divert overflow water to the garden when you are sure that it will all soak into your soil and not run next door.
- Overflow water from rain that falls during the dry season will be a particularly valuable addition to your garden. Every effort should be made to use every drop of it.
- One way of coping with a heavy flow of water during the dry season is to connect a length of flat hose to the tank outlet. The other end can be shifted around the garden during the rain. A good option for sloping sites is to run the water through a length of 50 mm slotted plastic drainage pipe laid out across the top of a slope. The water will trickle out through the many holes in the drainage pipe and so be spread across the garden.

This small pressure pump is all that is needed to pump water from a tank to a dripper or micro-sprinkler system.

- In areas of low average annual rainfall (certainly wherever the long-term average annual rainfall has been up to 500 mm; it is now rather less than this), it is also desirable to divert to the garden all or most of the rain that falls in the wetter part of the year. By allowing this to soak into your soil, you can fill up the subsoil with water. The deep-rooted, drought-tolerant plants that you will be growing will then have a better supply for the dry times.

For a small garden around a house of average size, it is entirely possible to provide all the water for the garden from rain plus greywater (see detail at the end of this chapter).

No cheating here!

The plants in these planter boxes are watered via built-in reservoirs that greatly reduce watering frequency. (Photo: a2zplanters)

The frequency of water application is different for different types of plants

The basic philosophy is that water is applied as infrequently as the plants being grown can tolerate, to hold off watering during and for some time after rain, and to decrease frequency as temperature falls. The range is as follows:

- **Vegetables** that are producing abundantly, and **potted plants:** daily in hot/dry periods to less frequently in cooler/wetter weather.
- **New plantings:** twice a week for two weeks if establishing them during cool weather, then gradually decrease frequency to that of established plants; daily for two weeks if establishing them in warmer weather. Including a water crystal slurry in the planting hole can reduce the need for extra water (see p. 110).
- **Fruit trees:** weekly during summer, but perhaps twice a week in the middle of a prolonged heat wave.
- **Ornamental plants of medium drought tolerance (see Table 10):** less than once a week in summer grading to none in winter.
- **Drought-tolerant ornamental plants:** never in many areas, grading to twice a summer and certainly no more frequently than once a month in the driest part of the year, unless they are planted densely. Each watering is to be of at least 60 mm.

Five simple steps to work out how much water to apply to different parts of your garden

To work out the amount of water to be applied to each area of your garden, you need answers to the following questions:

1. What is the drought tolerance of the plants in the area?
2. What was the average amount of water evaporation in your locality during the previous week?
3. What is the minimum quality level that you will tolerate for the plants in this area?
4. How much water does the irrigation system of this area deliver each hour?
5. What were the actual weather conditions during the previous week?

Detailed guidelines for finding answers to these questions are given below. Even if you are going to have a soil moisture sensor or an on-site weather station manage your irrigation system for you, it is still necessary that you have answers to questions 1, 3 and 4. Evaporation and local weather conditions are automatically covered by sensors and weather stations, but you must be able to set the

controller for each of the different areas of your garden according to plant needs and water delivery rates for each area.

Step 1. Drought tolerance of plants

General information about drought tolerance is given in Chapter 2, and specific information for lawn grasses is given in Chapter 12. Use this information in conjunction with the 'crop factors' in Table 10 to work out a watering schedule for different parts of your garden.

If you want vegetables, fruit trees, herbs and annual bedding plants to produce abundantly, you will have to treat them as if they cannot tolerate drought.

Of all the plants that you will want to grow in containers, only the succulents and cacti will survive if they are not watered frequently in summer.

It is absolutely essential that you group plants of similar water requirements. For example, a corner of drought-tolerant Australian native plants and exotics may never need to be watered after establishment, whereas a mixture of drought-tolerant and drought-sensitive plants would need repeated watering. This latter arrangement would use much more water than would separate plantings. What is more, the drought-tolerant plants could well have shortened lives through excessively rapid growth or the development of root rots.

Increasingly, plants in nurseries are being labelled according to drought tolerance.

If you know in advance that you will not be able to provide extra water to some of your plants, you could improve their chances of surviving summer by reducing their canopy size. Remove branches or just cut back foliage all around, whichever looks best.

Step 2. Evaporation of water in your area

Table 9 lists average evaporation rates for major Australian population centres, plus a few others for contrast. These figures are the depths of water that will evaporate from a 'Class A pan evaporimeter' in one week under average conditions for the location. Losses from plants will always be less than this, as you will see in the next section.

Evaporimeter operated by the Bureau of Meteorology.

Table 9. Approximate weekly depths of water evaporated from an evaporimeter in various parts of Australia (mm per week)

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mm
Coastal													
Hobart	30	27	20	13	9	6	6	8	14	19	24	27	1000
Melbourne	41	39	28	18	11	8	9	13	18	25	32	38	1500
Brisbane	39	35	31	26	18	16	16	22	29	34	38	44	1700
Adelaide	50	47	34	21	13	10	10	15	21	30	40	45	1900
Sydney	50	45	37	29	20	18	19	26	34	41	45	52	2000
Perth	57	54	43	28	19	14	14	17	24	35	39	44	2000
Townsville	58	51	49	46	38	35	37	43	54	62	64	63	2800
Darwin	45	41	43	48	50	49	50	53	56	58	55	49	2400
Inland													
Canberra	49	42	31	19	11	8	8	13	20	28	38	48	1800
Mildura	74	69	52	32	18	13	14	20	31	45	60	71	2100
Alice Springs	90	80	70	51	34	25	27	39	55	71	80	85	3000
Oodnadatta	115	105	85	58	38	28	32	43	60	81	99	113	3100

Source: Bureau of Meteorology; www.bom.gov.au

Step 3. Minimum plant quality tolerated

You need to decide what quality you would like your plants to have. At one end of the scale, the plants will look lush and be growing vigorously. At the other end of the scale, they will be just hanging in. Of course, if the plants have a high tolerance to drought, they can still look excellent, even though 'just hanging in'.

Research has shown that, when all types of plants are provided with unlimited water, they will use water at about 85% of the rate at which it is lost from a nearby pan evaporimeter. But when plants have access to less water than this, they use water at a lower rate. This decreases their growth rate, but it does allow them to 'stretch out' the supply in the soil. Highly drought-tolerant plants can in fact survive while using less than 20% of the water that is being lost from a nearby pan evaporimeter. We can express these numbers in another way. If we give the rate of loss from an evaporimeter as 1, a use rate of 85% of this will be given as 0.85 and 20% as 0.2. These numbers are called crop factors. Table 10 lists crop factors that are associated with different levels of plant growth and appearance.

How to use evaporation figures and crop factors

Using evaporation figures and crop factors is easy.

1. From Table 10, choose a crop factor that matches the type of plant growth you want.
2. From Table 9, choose evaporation figures for your area.
3. Multiply the appropriate evaporation figure by the crop factor to get the amount of water needed by your plants each week.

Example 1: vigorous lawns, Melbourne

You have one cool-season grass lawn and one warm-season grass lawn. If you decide that

Table 10. Crop factors for different types of plants that are being maintained to different levels of growth

Plants	Type of growth or appearance	Crop factor
Vegetables, fruit trees	Ample produce	0.85
Lawns, cool-season grass	Lush	0.8
	Strong growth	0.7
	Moderate growth, just acceptable	0.65
Lawns, warm-season grass	Lush	0.6
	Strong growth	0.5
	Some growth, just acceptable quality	0.3
Ornamentals	Establishment, vigorous growth, large-leaved	0.8
	Strong growth	0.65
	Moderate growth, somewhat drought-tolerant plants	0.4
	Low growth rate acceptable, plants drought-tolerant	0.2–0.4
	Minimum; desert plants	0.1–0.15

you would like them to put on strong, but not lush, growth, the crop factor for the cool-season grass is 0.7, and for the warm-season grass it is 0.5.

You can see (Table 11) that a lawn of warm-season grass will need much less water than a lawn of cool-season grass.

Example 2: drought-tolerant plants, Melbourne

You do not have enough water allocation to allow the cool-season grass lawn to continue. You decide to convert it to plantings of drought-tolerant plants, including some Australian native plants and some succulents. The crop factor for them is 0.2. You are prepared to accept a somewhat lower quality for the warm-season grass lawn, so the crop factor for it will be 0.3. The calculations will give the results shown in Table 12.

Now compare these figures with rainfall figures for Melbourne (Table 13).

You can see that established drought-tolerant plants should be able to survive without any extra water other than that provided by rain. For this to be possible, it is necessary that winter rain soaks into the soil for use during the drier months. (If you do not get much winter rain, your plants will struggle, but if truly drought-tolerant should survive.) The warm-season grass lawn may need no more than one deep soaking in January.

Step 4. Amount of water delivered by your irrigation system

The simplest way of finding out how much water is delivered by a section of your irrigation system is as follows:

Table 11. Results of calculations to determine weekly amounts of water to apply to lawns composed of cool-season or warm-season grasses that are growing strongly

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (mm/week)	41	39	28	18	11	8	9	13	18	25	32	38
Type of plants	**Amounts of water needed each week (mm) to maintain the chosen level of growth**											
Cool-season grass (crop factor 0.7)	29	27	20	13	8	6	6	9	13	18	22	27
Warm-season grass (crop factor 0.5)	20	20	14	9	5	4	5	6	9	12	16	19

Table 12. Results of calculations to determine weekly amounts of water to apply to a lawn composed of warm-season grasses of just acceptable quality and an area of drought-tolerant plants

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (mm/week)	41	39	28	18	11	8	9	13	18	25	32	38
Type of plants	**Amounts of water needed each week (mm) to maintain the chosen level of growth**											
Drought-tolerant plants (crop factor 0.2)	8	8	6	4	2	2	2	3	4	5	6	8
Warm-season grass (crop factor 0.3)	12	12	8	5	3	2	3	4	5	8	10	11

- Read the water meter. Water meters used in Australia read to 0.1 or 1 litre.
- Run the section of the irrigation system you are checking for exactly 10 minutes.
- Do not use any water elsewhere during the test period.
- Read the water meter again.
- The difference between the two readings gives you the number of litres of water that were delivered to this section of your garden in 10 minutes.
- Multiply the number of litres by six to get the number of litres delivered in one hour.
- Measure the area of the garden watered by this section of your irrigation system, in square metres. Pacing it out will do.
- Divide the number of litres delivered per hour by the number of square metres watered to get the number of litres delivered per square metre. This is the number of millimetres depth of water delivered.

Example

The number of litres delivered in 10 minutes was 50.

Table 13. Median weekly rain (mm)

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coastal												
Hobart	8	7	7	8	8	7	8	11	9	10	9	11
Melbourne	10	6	8	10	10	9	9	11	10	13	13	10
Brisbane	32	29	28	15	13	11	9	7	10	13	13	10
Adelaide	6	2	5	8	14	21	17	18	15	11	8	6
Sydney	18	20	21	20	20	23	13	11	12	12	17	13
Perth	0.5	1.5	2	9	14	41	39	30	16	10	5	2
Townsville	50	56	35	8	5	2	1	1	0.5	3	8	19
Darwin	102	88	73	19	1	0	0	0	1.5	13	35	54
Inland												
Canberra	12	13	8	8	10	8	9	11	13	14	14	10
Mildura	3	2.5	1.5	3	4	4	6	6	6	6	4	3
Alice Springs	3	4	3	0.5	2	1	1	0.5	0.5	5	5	6
Oodnadatta	2	3	0.5	0.5	1	1	0.5	0.5	1	1.5	1.5	3

Source: Bureau of Meteorology; www.bom.gov.au

This water meter reads 73 489.1 litres.

Therefore the number of litres that would be delivered in 1 hour is 6 × 50 = 300 L.

The area watered was 30 square metres.

Therefore the number of mm depth of water delivered was 300 ÷ 30 = 10 mm per hour (One litre spread over one square metre gives a water depth of exactly 1 mm).

Step 5. Putting it all together

Let us continue the example for Melbourne started above.

A very useful alternative for measuring the output of sprinkler systems is to use tin cans. You measure with a ruler the depth of water (in mm) caught in each can and then calculate an average. This method also gives you information about the uniformity of application from the sprinklers.

ANOTHER USE FOR THE WATER METER

From time to time you should look at the water meter when all devices that use water are turned off. If the meter is showing water use, you probably have a leak in the plumbing that must be found and fixed.

It is January.

The average evaporation figure for a week is 41 mm.

An area of shrubs of moderate drought tolerance is to be watered. The crop factor is 0.4, so you would apply 41 × 0.4 = about 16 mm of water.

The dripper system to this area delivers water at the rate of 10 mm per hour.

You therefore need to run the drippers for 16 ÷ 10 = 1.6 hours.

Variations

1. There were a couple of light showers during the week. None of this water penetrated to the soil through your mulch, so all the plants got was what fell onto their leaves. Transpiration would have been reduced during and after the showers. Reduce dripper running time by about 10%, to 1.4 hours.
2. There was a heavy shower during the week that delivered 8 mm. You can reduce the application from 16 mm to 8 mm. So you run the drippers for 8 ÷ 10 = 0.8 hour.
3. The maximum temperature on three days during the week was in the 38–42°C

range. The evaporation rate during these days would have been double the average. Evaporation could have been 45% higher than average for the week, i.e. 41 × 1.45 = 59 mm. So apply 59 × 0.4 = 24 mm of water. You need to run the drippers for 24 ÷ 10 = 2.4 hours.

4. Water use by moderately to highly drought-tolerant plants is least when they are allowed to become somewhat stressed between applications. Extend the times between waterings into the four-to-eight week range. Each application would be about two-thirds the sum of the calculated weekly amounts.

It is late March.

The average weekly evaporation figure is 28 mm.

Continue with the example of drought-tolerant shrubs used above. Crop factor 0.4, so weekly application needed is 28 × 0.4 = 11 mm.

You could run the drippers for a bit over one hour, but a preferred alternative (on the principle of deep, infrequent watering) would be to wait another week and then run the drippers for two hours.

Example for vegetables in Adelaide in January

Weekly evaporation is 50 mm.

Crop factor for vegetables 0.85.

Weekly water needed 50 × 0.85 = 42.5 mm.

Tank water is to be applied daily so that the vegetables are not set back. Daily application is 42.5/7 = 6 mm.

If the drippers deliver 12 mm/hour, they need to run for 30 minutes each day.

All your calculations will be useless if roots from next door suck large amounts of water from your garden. RootBarrier® is an effective, non-polluting way of preventing such 'theft'. (See www.rootology.com.au)

A suggested strategy

When you got to the 'Variations' section above, you probably started to think that this is all too hard. You realise that all the numbers are averages, and no week is average. Besides, evaporation figures for capital cities are measured in open areas near city centres or at airports. Your area may be higher and cooler, with lower evaporation, or it could be windier, with higher evaporation. Even within your garden, water loss rates will be higher on the north and west sides of the house than on the south and east.

Before you throw up your hands and decide to go back to guessing, try the following simple strategy.

- Start with simple calculations like those above, based on the information provided here for your area.
- For a few weeks, apply the calculated amounts of water.
- If all the plants are happy, recalculate watering amounts using lower crop factors. That is, put on less water each time or, preferably, extend the time between waterings.
- If they are still happy after a few weeks, try again decreasing the amount of water

Tap timers at their simplest (left, all it can do is turn off the system) … or (right) with the ability to be managed automatically with a soil moisture sensor. (Photo: Toro Australia)

applied or, better, for drought-tolerant plants, extend the time between waterings.

- But if your plants are showing stress, and you have the water allocation, increase the water amounts again.
- If you do not have enough water, you need to replace drought-stricken plants with others that are drought-tolerant.

All this becomes child's play if you are able to let a soil moisture sensor manage your watering for you, as outlined below.

Useful devices

Your simplest aid is a tap timer. These range in complexity from simple mechanical devices to quite sophisticated programmable electronic devices that can even be managed with a soil moisture sensor.

To automate the watering of multiple areas, you can choose from a wide range of programmable controllers. The cheapest hardware store lines generally have limited capabilities compared with those that can be purchased at specialist irrigation shops. If you are still able to use an automatic system, choose one with as many as possible of the capabilities listed in the box on p. 81.

Rain switches are small devices that can be added to controllers. They stop the controller from operating during rain and for a day or two afterwards (see www.smartwatermark.org for a list of approved sensors). Most do not take account of the amount of rain that has fallen. The delay until next watering still needs to be worked out manually. Soil moisture sensors provide a much more effective way of taking account of rain.

Soil moisture sensors are buried in the soil in a watering zone of your garden that is set to receive weekly applications of water during hot weather. This will usually be under a fruit tree. The sensor cancels scheduled irrigations

The Australian-made Watermatic soil moisture sensor is installed in the soil of an area that will be regularly watered. It has a proven track record from 20 years of use in sports turf applications, where it has consistently provided savings in water use of between 40 and 60% (compared with guessing or time-based application). (Photo: Cuming and Associates, Melbourne)

The Australian-made AquaBlu™ soil moisture sensor is an urban-horticulture version of a sensor that has been successfully used in irrigated horticulture for over 10 years. (Photo: AquaSpy Group)

The FullStop™ wetting front detector is used under fruit trees and vegetables, but not under more drought-tolerant plants.

when the soil is moist enough. The run times of the other zones are set to the needs of their plants relative to the first zone, using the crop factors listed in Table 10. The whole system is then self-controlling. Watering intervals are automatically decreased when the soil loses water more rapidly in warm weather, and increase as the weather cools or when rain falls. During extended periods when the soil is moist, the sensor prevents the controller from operating. These sensors will connect into any controller, and will be easiest to manage if the controller has the capabilities listed in the box on p. 81. Once set up, they eliminate the need to do all the calculations given earlier in this chapter. Trials in both the USA and Australia (Melbourne and Perth) have shown that correctly installed soil moisture sensors are more effective than weather-based methods for automatically managing watering.

Not all soil moisture sensors are created equal. With some of the cheaper ones, the reading changes as the salinity of the soil changes. They give different results in different soils. They may give satisfactory results if the salinity of your soil is fairly constant and you learn by trial and error how to manage them.

Keen growers of fruit and vegetables should have a look at the FullStop™ wetting front detector (www.fullstop.com.au). (The wetting front is the boundary between wet soil and the drier soil below it.) This simple device is **only** useful for plants growing in soil that is to be kept close to field capacity (see p. 50). It is **not** suitable for use under drought-tolerant ornamentals. It is very much an educational tool that will tell you what is happening in your soil when you apply water to it.

'SMART' IRRIGATION CONTROLLERS

The smartest controller for managing watering systems is you, the gardener, armed with the information just provided. You will know when to turn on the system and for how long to leave it on. However, there are some 'smart' controllers that can take out most of the hard work of managing a watering system.

The best 'smart' controllers have the following minimum capabilities:

- allow non-watering intervals of up to 30 days
- have separate programming for each station
- have multiple starts for each station
- have 'on' times of from one minute to four hours
- retain several programs in memory, even when the power goes off and the battery runs low (i.e. have a 'non-volatile' memory)
- allow different crop factors to be applied to each station
- are able to be programmed to comply with local water restrictions
- accept inputs from soil moisture sensors and real-time climatic data.

There are two ways in which a smart controller can be managed. Arguably, the simplest effective way is with a soil moisture sensor (above), the best of which have a proven track record of delivering excellent plant quality with the least water.

The other way of operating a smart controller is via information about recent weather (air temperature, air humidity, wind speed, intensity of the sun's radiation, water evaporation rate, rain). This information is either provided on a daily basis from the nearest weather monitoring service or from an on-site weather station. This method of operation is now widely used in the southern USA (see www.scwa.ca.gov and www.mwdoc.com for examples). These controllers are available in Australia and can be managed with information provided via an internet connection to www.bom.gov.au (the Bureau of Meteorology). This method of operation will be most reliable when the BoM weather station is within a few kilometres of your garden. While this way of operating a controller can give excellent results, it has been found that a high level of user attention is needed if the system is to deliver the water savings that it is capable of providing.

If you do decide to operate a controller via a soil moisture sensor or with weather data, you still must set each watering station for the types of plants watered by it. You must fine-tune the system by going through the strategy suggested above. The whole system must be checked regularly for leaks, blockages, malfunctions in the controller and solenoid valves, and so on.

The Weathermatic® 'smart' irrigation controller is managed by a soil moisture sensor or by a weather station that you install on your roof gutter, as shown.

IT IS EASY TO WATERPROOF A MEDIUM-SIZED GARDEN

This example uses data for Perth and Sydney. For both cities, the average summer (October to April, inclusive) pan evaporation (from Table 9) is about 1200 mm. The amounts of water required to maintain gardens will always be lower than this. For this example they will range from:

- 15% of these figures (highly drought-tolerant species grown – crop factor 0.15), through
- 30% (plants with moderate drought-tolerance – crop factor 0.3), to
- 40% (mixed garden with some drought-tolerant species, some less tolerant ornamental plants and some vegetables and fruit trees – average crop factor of 0.4), and
- 80% (vigorous lawns, high-water use ornamental plants – crop factor 0.8).

To calculate the amounts of water needed for a 200 m^2 garden in Perth or Sydney, multiply 1200 mm evaporation by the 0.15, etc., crop factor x 200 m^2 area and divide by 1000 L/kL. The calculated amounts of water required in summer are 36, 72, 108 and 192 kL (1 kL = 1000 L), respectively, for these types of garden areas. Tables 14 and 15 show average amounts of water needed to supply the needs of these four different types of plant communities.

These figures show that highly drought-tolerant plants should need no extra water if rainfall for the period is at least 180 mm. Moderately drought-tolerant plants should need no extra water if rainfall is at least 350 mm. On average, Perth receives just 120 mm of rain during the October to April period, while Sydney (airport) receives 484 mm. These amounts of rain would supply, on average, 24 and 97 kL to a 200 m^2 garden in Perth and Sydney, respectively. So in Perth even drought-tolerant plants will need some greywater or tank water during summer. In Sydney, it is possible to have a garden of moderately to highly drought-tolerant plants with rain only, except in years when summer rain is well below average.

For a mixed garden in which some fruit and vegetables are being grown, all greywater and

Table 14. Some figures for water inputs and use by a 'typical' suburban house: block 600 m^2; house and shed 300 m^2; paved areas 100 m^2; garden 200 m^2. The figures are to be compared with summer water requirements (October to April, inclusive) of 36, 72, 108 and 192 kL for 200 m^2 of highly drought-tolerant, moderately drought-tolerant, mixed, and lush plantings, respectively, for Perth and Sydney

Rainfall during summer (mm)	Rain falling on roof* (kL)	Rain falling on garden area (kL)	Greywater potentially available for garden^ (kL)	Rain falling on garden plus all greywater diverted to it (kL)	Rain falling on garden, plus all greywater, plus 10 kL from tank (kL)
0	0	0	70	70	80
100	30	20	70	90	100
200	60	40	70	110	120
300	90	60	70	130	140
400	120	80	70	150	160
500	150	100	70	170	180

* Rain falling on paved areas is one-third of these amounts.
^ From www.health.nsw.gov.au for an 'average' household of three people.

Table 15. Extra water needed above that supplied by rain falling on the garden plus all greywater and 10 kL of tank water, as listed in the last column of Table 14 (kL/summer)

Rainfall during summer (mm)	Highly drought-tolerant plants (need 36 kL)	Moderately drought-tolerant plants (need 72 kL)	Mixed garden (need 108 kL)	Lush garden (need 192 kL)
0	0	0	28	112
100	0	0	8	92
200	0	0	0	72
300	0	0	0	52
400	0	0	0	32
500	0	0	0	12

some tank water will be needed in both Perth and Sydney. Some municipal water will also be needed in Perth. A lush garden would need considerable amounts of municipal water, even if all greywater and some tank water is used.

Waterproofing a garden becomes easier as garden size decreases in relation to house size. In contrast, larger gardens will need proportionally more water than the amounts listed here. It will be increasingly difficult to maintain a garden without municipal water as its size increases. Only with a rainwater storage capacity in the 30–100 kL range might this be possible. That is the range from a farm-size tank up to a large swimming pool.

Rain is the best. (Photo: Eleanor Handreck)

GARDEN WATERING SYSTEMS

KEY POINTS

Buckets and watering cans

Hoses

Hand-held and fixed sprinklers

Drip systems

There are six main types of systems for watering gardens:

- buckets and watering cans
- hand-held hoses
- sprinklers connected to hoses and moved by hand
- fixed sprinklers
- drip systems
- sub-irrigation (see p. 143).

Buckets and watering cans

Buckets and watering cans are hardly a watering system, but wherever water restrictions make it illegal to use any hand-held hoses, fixed sprinklers or drippers, this highly inefficient way of watering plants may be your only option for providing some municipal water to your plants.

Here are guidelines which will help you get the most out of buckets and watering cans.

- Form shallow earth walls around each of the plants you want to water, so that the bucketed water is retained where it will do the most good. You will no doubt already have mulch on the soil. The plant will get the greatest proportion of the water if you can pour the water so that it spreads under the mulch. Water retained in the mulch itself will only evaporate again.

Water can be retained around young plants either with an earth dam or with a GreenWell™.

A simple drip system for bucketed water.

- If it is legal in your area, you could rig up a dripper system that is fed from a pail or drum sitting on a stool. You fill the drum from a bucket and the water slowly flows to the soil under a few prized plants. Because drippers are designed to operate at a higher pressure, the drip rate will be very slow, but nevertheless sure. Adjustable drippers (e.g. Octa) will work with a low head of water, and are easy to clean if they become clogged.

Plastic water-filled traffic barrier slowly watering a large tree in Melbourne during the 2006–07 summer. (Photo: Geoff Connellan)

- Even simpler is to allow water to slowly drip from a plastic container that has a tiny hole formed by inserting a hot needle through the side near its base.
- If you are not allowed to use any 'new' tap water on the garden, you can still provide extra water to your plants via rainwater stored in a tank or via greywater.

Hand-held hoses

Note that water supply authorities require that a hand-held hose must end with a trigger sprayer that automatically shuts off when you do not hold it. Most trigger sprayers have a number of settings. Trials at the University of Melbourne, Faculty of Land and Food Resources campus at Burnley (previously the Burnley Horticulture College) have shown that on the 'shower' setting, the rate of water delivery can be around 1000 mm/hr if all the water were to go onto the same area. This is at least 20 times the ability of most soils to absorb water, so you must move the spray around. Unless you move systematically, the area will be watered unevenly. When this is combined with the inevitable boredom associated with hand watering, the typical outcome is that the water rarely penetrates more than a few millimetres into the soil. Repeated light sprinklings that penetrate no more than a few millimetres encourage shallow root production and are just a waste of water. In fact, all of the water can be wasted if the soil is covered with a fine mulch that retains all of the water (see p. 98). While studies in Sydney have shown that, for small areas of small gardens, hand-held hoses can be effective, this will happen in drier areas

Trigger sprayer.

Several types of micro-sprinklers.

only if you apply at least 20 mm depth of water on each occasion.

Sprinklers on hoses

Where they can be legally used, sprinklers on the ends of hoses offer more flexibility than buckets or hand-held hoses. The main disadvantage is that you need to be there to shift them and turn them on. Tap timers allow automatic turnoff.

Fixed sprinkler systems

In fixed sprinkler systems, the pipes carrying the water to the sprinklers are permanently installed in the soil or on its surface. In-ground installation is essential for lawns. Both in-ground and surface installation can be used in garden beds. Micro-sprinklers that spray water under trees and shrubs often give better coverage in garden beds than do larger fixed sprinklers, whose water can be intercepted by foliage. A solenoid valve is installed between the mains water supply and the pipe system serving an area of the garden. This solenoid valve is connected electrically to a controller that can be programmed to switch on a number of valves in sequence, starting at a time that is programmed into the controller. Each area can be separately switched on for a specified time.

Advantages

- Compared with sprinklers that have to be moved by hand, they save a lot of time.
- Watering is taken care of even when you are away from home.
- If they are well designed, they water evenly and thoroughly. Well-designed systems are the next best thing after rain.
- Watering can be programmed for the period before sunrise when evaporation losses are lowest.
- Watering can be programmed to take account of the infiltration rate of the soil.

Disadvantages

The main ‘disadvantage’ is that the use of fixed sprinkler systems is now banned in many parts of Australia. The principal reason given is that losses by evaporation from water droplets as they fly through the air make all sprinklers more wasteful of water than are drippers. The reasoning apparently is that by using drippers,

gardeners will use less water than if they were allowed to use micro-sprinklers. This is not necessarily true. The Sydney survey quoted in Table 22 (p. 118) showed that many gardeners applied much more water than their plants needed no matter whether they delivered the water via micro-sprinklers or drippers. This was put down to poor system design and lack of understanding of the systems, rather than to any inherent inefficiency in them. Both micro-sprinklers and drippers can be efficient methods of watering when they are used in accordance with the guidelines provided in Chapter 7. However:

- Losses can be large from some pop-up systems whose sprinkler heads produce very fine droplets and mist that is simply blown away. The cause is the use of the wrong sprinkler heads and/or operation at too-high pressure. The readily available gear-driven sprinklers that operate at lower pressure and deliver medium-sized drops are best.
- The combination of micro-sprinklers and a thick layer of fine organic mulch is a sure recipe for wasting water. Most of the water will be retained in the mulch and will simply evaporate again (see p. 98).
- If you are still able to use a fixed sprinkler system, you must:
  - regularly inspect it for leaks or blockages and fix these as needed,
  - use the information in Chapter 7 to set the controller to deliver only the minimum amounts of water needed by the plants in each area, or
  - use a smart controller and other devices discussed in Chapter 7.

Other considerations for sprinkler systems

- Eliminate runoff by adjusting the rate of watering to below the infiltration rate of the soil. For most soils that means that the application rate should be less than 20 mm per hour, and for some, less than 10 mm per hour. Many older pop-up sprinkler systems deliver about 50 mm per hour. Their 'on' periods must be short and interspersed with 'off' periods to allow infiltration. For example, you could set the controller to run the sprinklers on a 15-minutes-on, 30-minutes-off cycle until the required amount of water has been delivered.
- Drippers are to be preferred over sprinklers if your water is very salty.
- It is strongly recommended that if you intend to install a fixed watering system yourself, you should have it designed by an irrigation professional, or at least have your design checked by such a person. Poor design is a common cause of watering systems giving poor performance.

Drip systems

The key part of a drip irrigation system is a 'dripper' or 'emitter' from which water can flow at a slow rate. Drippers are either already installed by the manufacturer into polyethylene pipe or you buy them separately and install them into black poly pipe yourself. The dripper line is run out across the area to be watered and then buried under the mulch. The water is applied straight onto the soil surface.

Even if you get a contractor to do the design and installation for you, the information

(From top:) Netafim™ Techline™, Toro Drip Eze™.

Some of the components of a dripper system (clockwise, from top left): adjustable solenoid valve; one type of filter; air release valve; flush valve; pressure reducer.

provided here will enable you to interact effectively with the contractor so that the best possible outcome is achieved. Where you cannot use dripper systems to deliver municipal water to your plants, you can use the information to design systems for delivering greywater or rainwater. If you intend to 'DIY', you should still get your design checked by an irrigation professional (see www.irrigation.org.au for more information).

Drip system design

The essential components of a drip watering system are:

- a water supply
- a backflow prevention device for municipal supplies
- tap timer or a programmable controller (For dripper systems the controller must allow operating times of at least two hours and preferably up to four hours. Having long run times for clay soils allows you to water deeply and hence as infrequently as a couple of times per summer)
- solenoid valve with flow control
- wires to connect the controller to each solenoid valve
- in-line filter that can be easily accessed for cleaning
- in-line pressure reducer. The flow control on the solenoid valve may be sufficient
- poly pipe containing drippers that is laid out under the mulch under your plants
- joiners and clips for the poly pipe
- a valve to allow flushing.

Main advantages of drippers

- Evaporation losses are reduced compared to those from sprinklers.

- The root zone of the plant can easily be kept near field capacity; plants therefore keep growing at their maximum rate. This is good for vegetables and fruit trees, which will produce most abundantly when the required amount of water (see p. 72) is applied every few days. The watering strategy **must** be different for ornamental plants, as given in the box.
- Salts in water are washed to the outer margin of the wetted zone. Therefore water of higher salinity can be used than is possible with sprinklers.
- Dripper lines are easily controlled automatically.
- Drippers are useful for difficult-to-water areas such as steep slopes.

Some disadvantages

- Drippers need to be checked regularly for blockages.
- You can easily waste large amounts of water with a drip system. Use the information here and in Chapter 7 to set the length and frequency of 'on' times.
- Too few drippers per plant, especially in sandy soils, will restrict root growth and allow plants to be more easily blown over.
- Operating drippers under established ornamental shrubs and trees in the same way as under fruit trees will waste large amounts of water (Table 10). Don't run established ornamentals and fruit trees on the same line if you want to save water.
- A filter is essential if the water source is a surface dam or greywater and highly desirable with municipal water supplies.

DRIP WATERING OF DROUGHT-TOLERANT ORNAMENTAL PLANTS

A key strategy in having an attractive garden even when the use of municipal water is severely restricted is to grow moderately to highly drought-tolerant plants (see Chapter 2). These plants can still look attractive with rain only, or rain plus a small amount of extra water. They do this in part by producing extensive root systems that penetrate deeply into the soil, and in part by having hard leaves that still look much the same even when the plant has to 'shut down' because of low water supply. Towards the end of the dry season in their native habitats these plants may have shed leaves. The remaining leaves may be pale, with a 'hang-dog' look. Some individuals will have died. We do not want to have this happen in our gardens, so we generally must apply at least some extra water.

The least water is used by drought-tolerant plants if you allow them to become water-stressed between irrigations. This is not achieved by watering them once a week via drippers. Rather, they should be watered infrequently, with each application being enough to penetrate deeply into the soil. Where you are only able to water once a week, it would be best to rotate applications amongst several areas. Rather than give all plants some water each week, you use all of your allowed watering time for a week on one area, then on another area the next week. Watering intervals of up to four to eight weeks should generally give satisfactory results. This strategy assumes that your soil is deep enough to hold within the plants' rooting depth all of the water provided, and that the infiltration rate is high enough to allow it to all soak into the soil.

- If you notice wilting on only one side of a tree or shrub that is watered via drippers, suspect that a dripper has blocked. Check and fix.

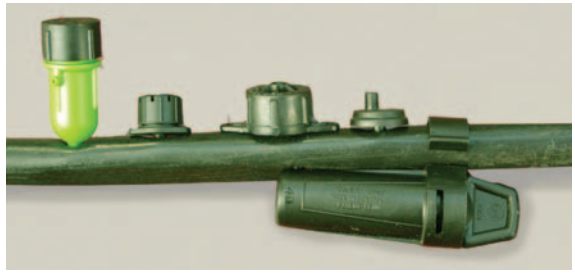
Types of drippers

There are several basic types of dripper systems.

The simplest to install are those in which drippers are already incorporated into poly pipe by the manufacturer. The drippers are typically 30 cm apart. Two variations are available: pressure-regulated and unregulated. Because you probably do not know the pressure of your water supply and because of some variation along dripper lines, it is strongly recommended that you use only regulated (pressure-compensating) dripper lines. You should also install a pressure reduction valve. Lines whose drippers each deliver 1.6, 2.0 and 2.3 L/hour are available. Some products are designed for installation in the soil below lawns. Their drippers are treated so as to prevent root entry.

In the second main type of dripper system, individual drippers are inserted into black poly pipe. Use only those that are pressure-regulated. While this system takes longer to set up, it is more versatile than the manufactured dripper lines for some applications. You can put the drippers where you want them and leave them out where there is no need to apply water. This system is excellent for plants in containers and when isolated shrubs are to be watered. Drippers that deliver 2, 4 and 8 L/hr are available. Check flow rates as illustrated, or by holding a film canister (volume 35 mL) under a dripper for a known number of seconds. Alter water pressure if the drip rate is too high or too low.

Weeper hoses made from old tyres are a type of dripper system in which water leaks out all



From left: two types of adjustable drippers; two non-adjustable drippers (the cap on the third from the left can be replaced with a blank cap if a dripper is temporarily not needed); beneath pipe: non-adjustable dripper. All but the dripper at top right can be opened for clearing blockages.

Dripper line for greywater is lilac-coloured and has larger dripper holes than 'normal' line.

Checking flow from a dripper.

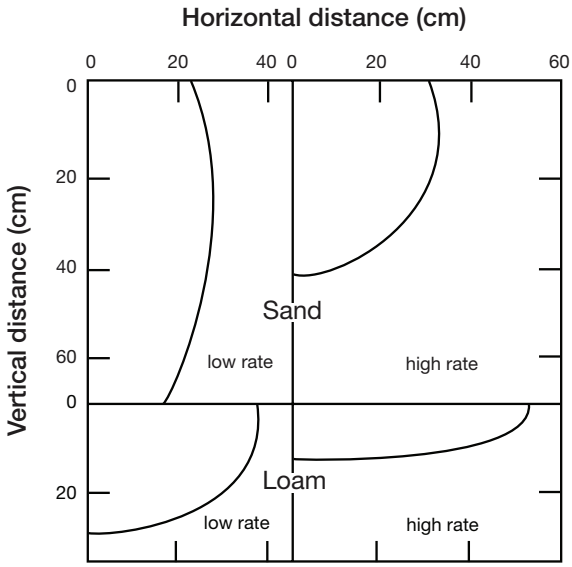
along the hose. Australian trials have shown that discharge rate can vary by eight-fold along a 9 m length. Water delivery rate can be very high at normal domestic water pressures. If you do decide to use them, you **must** check flow rate (use the water meter) and only water long enough to give the amount of water needed. Clogging may necessitate annual replacement.

Watering patterns for different soil textures

Sprinklers can deliver water fairly evenly to the whole area being watered. In contrast, drippers put water onto the soil at separate points. Much of the water from a dripper moves straight down through the soil. The amount that moves sideways depends on the texture of your soil, the rate of delivery and the slope of the site. Typical wetting patterns are shown in the diagram.

Note that:

- There is more sideways movement of water in loam and clay soils than in sandy soils.
- Increasing application rate allows more sideways movement, especially in clay soils. This is because some of the water ponds on the soil surface and flows sideways before it soaks into the soil.
- To maximise lateral movement of water in sands, use drippers that deliver 2–3 L/hr. Delivery rates for loams should be in the 1.5–2.5 L/hr range and for clays 1–2 L/hr. This means that to supply the same amount of water per unit area of soil, delivery times will be shorter for sands than for heavier soils. Use the information in Chapter 7 to work out 'on' times.



Wetting patterns under drippers.

Spacing of lines

In dry weather, plant roots will be getting most of their water from these wetted patches of soil. If your plants are to get enough water, the dripper lines must be spaced closely enough for the plants to get enough water during the chosen watering period. Here are some suggestions:

- For narrow beds up to about 0.5 m wide, as between a fence and driveway, one dripper line running the whole length of the bed is enough.
- For wider garden beds of rectangular to square shape, run two or more parallel lines of drippers. Have the dripper lines 20–25 cm apart on sands, 30–50 cm apart on loams and 40–70 cm apart on heavier soils.
- For garden beds of irregular shape, either run parallel lines in the middle of the area

An installation of the Irritrol Drip-In™ system under a new lawn area. Each dripper has been impregnated with a tiny amount of the herbicide Treflan. Long-term use in the USA has shown that roots are excluded for at least 18 years.

and fill in around the edges, or roughly follow the shape of the bed.

- For fruit trees and isolated trees set in lawns, run circles of dripper line around each tree, out to the edge of the foliage if possible.
- For bedding plants and vegetables, run one or two dripper lines along each row of plants. Using two lines allows you to stagger the drippers so that you can have the plants closer together. Space lines no more than 20 cm apart.

Line length per run

The low rate of delivery of water from each dripper means that you can have quite long dripper lines. The maximum number of drippers that can be run depends on water pressure, pipe diameter and dripper rating. For operation within the designed water pressure range of 50–400 kPa, you can run up to 100 m of 1.6 L/hr drippers in 13 mm pipe and up to 75 m for 2 L/hr drippers. You would probably not exceed a quarter of these lengths when all the drippers are rated at 8 L/hr.

Adjustable drippers are needed for containers.

Run times for drippers

Drippers should be run only for the length of time that will deliver the required amount of water to the area, as calculated with the information provided in Chapter 7. The general guidelines are:

- For fruit trees, run the drippers each week during summer.
- For ornamental plants of moderate drought tolerance, run them every two to three weeks for times calculated with a crop factor (see p. 75) of about 0.45.
- For drought-tolerant plants, run them every four to eight weeks for times calculated with a crop factor of about 0.2.

This *Beaucarnea recurvata* (Ponytail Tree) is easily maintained in a large planter bed via a circle of dripper line.

Yates Tuscan planters have a built-in water well.

Drippers for pot plants

Here is some essential information to ensure that you can successfully use drippers to water plants in pots:

- The very open nature of good potting mixes means that there is only limited sideways movement of water. You need to either have some means of spreading out the water across the surface of the mix or you need to use more than one dripper per container.
- So that you do not waste water, use adjustable drippers so that you can regulate the amount of water being applied to each container.
- For containers of 1–4 L capacity, one dripper per container will be enough.
- There are two options for larger containers:
  - have one dripper each side of the plant stem, or
  - have a circle of dripper line around the stem, where more than two drippers are needed.

Dripper lines among decorative potted plants are fairly ugly. An alternative that minimises watering effort is to use pots that include water wells that can supply water for up to a month.

One of the extensive range of 'self-watering' planters from The Container Connection.

MULCHES: THE FACTS

KEY POINTS

Myths about mulches

Facts about mulches

Where to use organic and inorganic mulches

Coarse mulches are best

Mulch is a layer of material on the surface of a soil. A mulch may consist of:

- some of the soil itself. The dry upper part of a gravelly or sandy soil is an excellent mulch. Some clay soils self-mulch as they dry out. Light raking of other soils after every rain or irrigation can create and maintain such a layer.
- organic materials such as wood chips, chunky pine bark, green organics composts, cereal straw, pea straw, bagasse (sugarcane mulch) and so on.
- a layer of inorganic material such as scoria, gravel, water-worn pebbles, crushed lateritic rock (WA) or crushed bricks.

Loose surface soil makes an excellent mulch around this Wreath leschenaultia in inland Western Australia.

Myths about mulches

Myth 1. Organic mulches should be spread around **all** garden plants and to depths of 70–100 mm. Many gardening books, retail packs and most water authority websites make this sort of recommendation. The factual information provided on the next few pages will show you that this is not universally sensible and, for some organic mulches, is totally silly.

Myth 2. Organic mulches will reduce water loss from a garden by up to 70%. While it can be true that a dry organic mulch will reduce evaporation from moist soil below it by 70%, the plants growing in the soil will still be

Organic mulches (from top): coarse pine bark, hoop pine bark, chipped wood in three colours.

Maybe not everyone's idea of a colour scheme.

transpiring water. Factual data for Sydney show that organic mulches reduce total water use in a garden by no more than about 10%. That can, of course, be very useful when water restrictions are severe. But note other facts below about the interaction between organic mulches and rain.

Myth 3. Mulches are improved by the addition of a wetting agent.

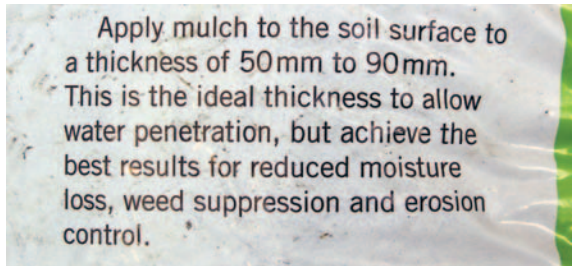
Mulches and water

A main benefit provided by mulch to gardeners and their plants is its ability to reduce the loss of water from the soil. The way mulches do this is much the same as the way a blanket keeps us warm at night. The layer of still air within the blanket slows down the movement of warmth from our body to the general atmosphere. The layer of still air within a mulch slows down the movement of water vapour from the soil surface to the air above.

You might think therefore that the thicker a mulch, the greater the reduction in water loss.

Inorganic mulches (from top): three types of water-worn stones, crushed rock, crushed bricks.

Some mulch bags have sensible instructions …



… others do not.

If only life were that simple. Mulches are much more complicated than that. The main complication is their interaction with rain. Mulches hold water. The thicker a mulch, the higher will be the proportion of any rain that is retained. This water does not reach plant roots in the soil below. Here are some guidelines from research on organic mulches.

Coarse wood chips make an excellent mulch.

Water held by organic mulches

As shown in the next two tables, fine mulches to which a wetting agent has been added can retain large amounts of rain.

Table 16. Effect of particle size on rain held by wood chip mulches

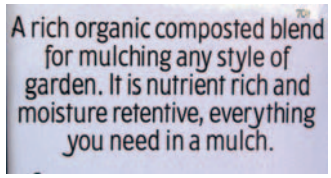
Particle size range (mm)	Rain held by 35 mm thick mulch (mm)	
	Water-repellent mulch	Wetting agent added to mulch
>12	2.5	2.7
6–12	3.0	3.0
5–6	3.1	3.3
2–5	5.3	7.1

Table 17. Effect of fine particles on rain held by wood chip mulches

Percentage of particles smaller than 2 mm	Rain held by 35 mm thick mulch (mm)	
	Water-repellent mulch	Wetting agent added to mulch
30	4.9	5.3
50	5.8	8.1
70	7.7	18.6
75	8.6	21.1

These tables show that:

- Mulches whose particles are all larger than 5 mm retain only modest amounts of rain. Wetting agent has little effect on the amount of water held by them.
- Any inclusion in the mulch of particles smaller than 5 mm increases the amount of water held. However, if the mulch is water repellent, the increase is modest.
- Mulches with high proportions of easily wet fine particles hold large amounts of water.
- According to the figures given above, a 70 mm thick layer of fine mulch, as is widely advocated, could hold **all** of the water provided by a rain event or sprinkler application of up to 42 mm!
- A 100 mm thick layer of fine mulch that has had a wetting agent added to it could trap up to 60 mm of rain or sprinkler water before any water reaches the soil.



Actually, moisture retentive mulch is not what you need.

Where rain falls as infrequent light showers, fine organic mulches will prevent **all** rain from reaching the soil below.

Mulches with high proportions (greater than 80%) of particles larger than 5 mm are best at letting rain reach the soil below them. But how do they perform in reducing evaporation? The next two tables give information for the mulches listed in Tables 16 and 17.

Table 18. Effect of mulch particle size distribution on water loss from moist wood chip mulches

Particle size range (mm)	Water lost from water-repellent mulch for the first six days after rain (mm)	
	35 mm deep	70 mm deep
>12	4.6	4.3
6–12	4.1	4.5
5–6	3.6	3.9
2–5	3.0	3.6

Unmulched soil lost 11.8 mm.

This table shows that:

- For the coarse mulches (all particles larger than 5 mm), changes in particle size distribution had little effect on water losses.

- Doubling mulch thickness for these coarse mulches did not reduce water losses, so with these coarse mulches there is no need to spread them any deeper than 35 mm.

Table 19. Effect of fine particles and wetting agent on water loss from moist wood chip mulches

Percentage of particles smaller than 2 mm	Water lost from 35 mm deep mulch in the first six days after rain (mm)	
	Water-repellent mulch	Wetting agent added to mulch
30	7.0	7.4
50	7.4	9.2
70	7.7	17.7
75	7.8	19.1

Unmulched soil lost 14.5 mm.
Shaded cells: water loss was greater than from unmulched soil.

This table shows that:

- As the proportion of fine particles increases, losses of water from the water-repellent mulch changed little, but increased greatly when wetting agent had been added to the mulch.
- As the proportion of fine particles in a water-repellent mulch increases, water loss increases only slightly. This is because the particles at the surface of the mulch dry out and so act as a mulch on top of the mulch.
- But when the mulch has had a wetting agent added to it, water loss increases greatly as the mulch becomes finer. This is partly because these mulches hold much water, but they also allow water to wick up through them from the soil below, as is shown in the next tables.

So far the tables have been about the response of mulches to water from rain or sprinkler irrigation. What are the losses when the mulch is initially dry and irrigation is via drippers placed beneath it? Here is some information.

Table 20. Effect of particle size on losses of water through dry, water-repellent organic mulches sitting on constantly moist soil

Percentage of particles smaller than 2 mm	Water lost (mm) through water-repellent mulch 35 mm deep	
	First week	Second week
0	7.3	6.8
10	7.5	7.3
30	7.1	7.4
50	7.1	7.5
70	10.9	12.7
75	11.1	12.6
Control (no mulch)	17.5	18.2

This table shows that:

- For water-repellent mulches, only those mulches with high proportions of fine particles have higher rates of water loss than have coarser mulches.
- The best (coarse, water-repellent) mulches reduced water loss by up to 63% ((18.2 – 6.8) × 100 ÷ 18.2). The worst (finest) only reduced it by about 40%.

Table 21. Effect of particle size on losses of water through dry, water-absorbing organic mulches sitting on constantly moist soil

Percentage of particles smaller than 2 mm	Water lost (mm) through mulch 35 mm deep that had been treated with wetting agent	
	First week	Second week
0	8.5	7.2
10	7.8	6.6
30	8.9	6.7
50	9.8	7.0
70	20.3	19.3
75	21.6	19.8
Control (no mulch)	17.5	18.2

Shaded cells: water losses were greater than from the unmulched soil.

This table shows that:

- When a mulch is easily wet, a high proportion of fine particles allows the mulch to actually lose water at a faster rate than bare soil (shaded areas of the table). These mulches are in fact anti-mulches. Some mulches sold in retail packs are like this.
- These fine mulches lose water rapidly because they allow capillary rise of water from the soil below. Many of the spaces in these fine mulches are filled with water, so there is no still air to break the contact between water in the soil and the atmosphere.

Conclusions for organic mulches

The main take-home messages for organic mulches are:

- They should have more than 80% of their particles larger than 5 mm and very little dust. These coarse mulches simulate the litter on a forest floor. There, the coarse, recently fallen leaves, branches and twigs sit on top of earlier falls, which have become finer as small animals and microbes have used them as food.

Natural mulch under ferns, Lord Howe Island.

- If we follow this line of reasoning, a useful technique for a soil that has little organic matter in it would be to first spread fine mulch or soil conditioner over the soil and then top it with coarse mulch.
- There is no need to spread them to a depth of 70–100 mm as is often advocated. A 50 mm thick layer is enough.
- The finer the mulch, the shallower should be its depth. Fine mulches spread deeply will prevent much rain from reaching plant roots and may even increase water loss from the soil below.
- They are best if they are water repellent.
- Including a wetting agent in fine mulches causes them to retain a high proportion of rain or sprinkler water and also allows them to suck water out of the soil.

Other very important facts about organic mulches

Natural ecosystems have a very wide range of amounts of leaf litter (mulch) on their soils. Here are some comments for specific ecosystems:

- At one end of the range are desert areas where cacti and succulents grow. Rocks are the main, and highly effective, 'mulch'. This suggests that organic mulches should not be spread under such plants. In fact, research has shown that applying organic matter actually harms these plants.
- Even in the less harsh areas where other drought-tolerant plants grow, the litter layer (mulch) on the soil surface is generally quite sparse. In gardens, these plants might benefit from a thin (25 mm) layer of wood chips or other coarse organic

Gravel and loose sand are the mulches of dry areas (from top): *Stylidium elongatum* in south-western Western Australia, *Didierea madagascariensis* in south-western Madagascar.

matter during establishment, but natural leaf and twig drop after that should be all that they need.

- In the native high-rainfall habitats of many cool-climate, drought-sensitive plants, the soil surface is covered with a thick layer of organic matter. For their best growth in gardens, they need to be provided with similar amounts of organic matter, but of course in areas of lower rainfall than the native habitat, thick, fine mulch will probably prevent almost all rain from reaching the soil.

Other important facts to note are:

- Fine organic mulches made from thoroughly composted materials will not contain weed seeds, but they do make excellent seed beds for any weed seeds that blow in. Weeds are less of a problem with coarse mulches.
- Strong positive effects are seen when fruit trees and vegetables are mulched with nutrient-rich organic materials.
- Natural leaf litter is very low in plant nutrients. Plants remove most nutrients before they shed leaves. If you apply organic mulch that is rich in plant nutrients, especially nitrogen and phosphorus, to drought-tolerant plants, you will over-stimulate them and so **reduce** their ability to cope with drought. Reserve these high-nutrient mulches for fruit trees and vegetables.
- Application of thick layers of organic mulch to drought-tolerant plants encourages their roots to grow up into the lower part of the mulch. What is really needed is to encourage them to grow roots deep into the soil by infrequent deep watering, or just leaving it to rain.
- Observation in environments from central Queensland to Victoria has shown that no harm is done to trees and shrubs when coarse mulch of maximum desirable thickness (up to 50 mm) goes right up to their trunks. Maybe the injunction to keep organic mulches away from trunks is sensible for thick layers of fine mulches in constantly wet environments.
- Snails and slugs shelter and breed in organic mulches. Use traps or baits to eliminate them.

Snails like the beer used to bait this snail trap.

- In bushfire-prone areas, organic mulches may contribute to fire intensity.

Extra comments on organic mulches

Woody organic mulches such as pine bark (composted or not), wood chips (coloured and natural), chipped tree branches and screened composted green organics will last for many years. Crop residues such as cereal straw, pea straw, sugarcane residues and baled lucerne will last for only one season, so they are useful for mulching annual crops such as vegetables. Pelleted organic materials usually fall apart to give a very fine mulch.

Sugarcane mulch.

Living alternatives to mulch (from top): small *Minuria* daisy bushes and *Carpobrotus modestus* (Inland Pigface). (Photos: Eleanor Handreck)

Do not use:

- anything that is likely to attract flies
- wood chips from diseased trees and shrubs
- diseased wastes, such as the remnants of tomato and zucchini bushes at the end of a growing season
- pure lawn clippings or autumn leaves (because they pack down into a dense mat that allows little water to reach the soil).

Either compost these to make soil improve or mix them with coarser materials such as chopped tree prunings and corn stalks
- sawdust (because it will retain a high proportion of water from light showers and so reduce the amount reaching plant roots).

Ground cover plants act as a living mulch. They will of course transpire water, but they do reduce water loss from the soil itself by shading and acting as a blanket. But don't use them where their water use will rob water from plants that have greater need for it.

Non-organic mulches

The main non-organic mulching materials are:

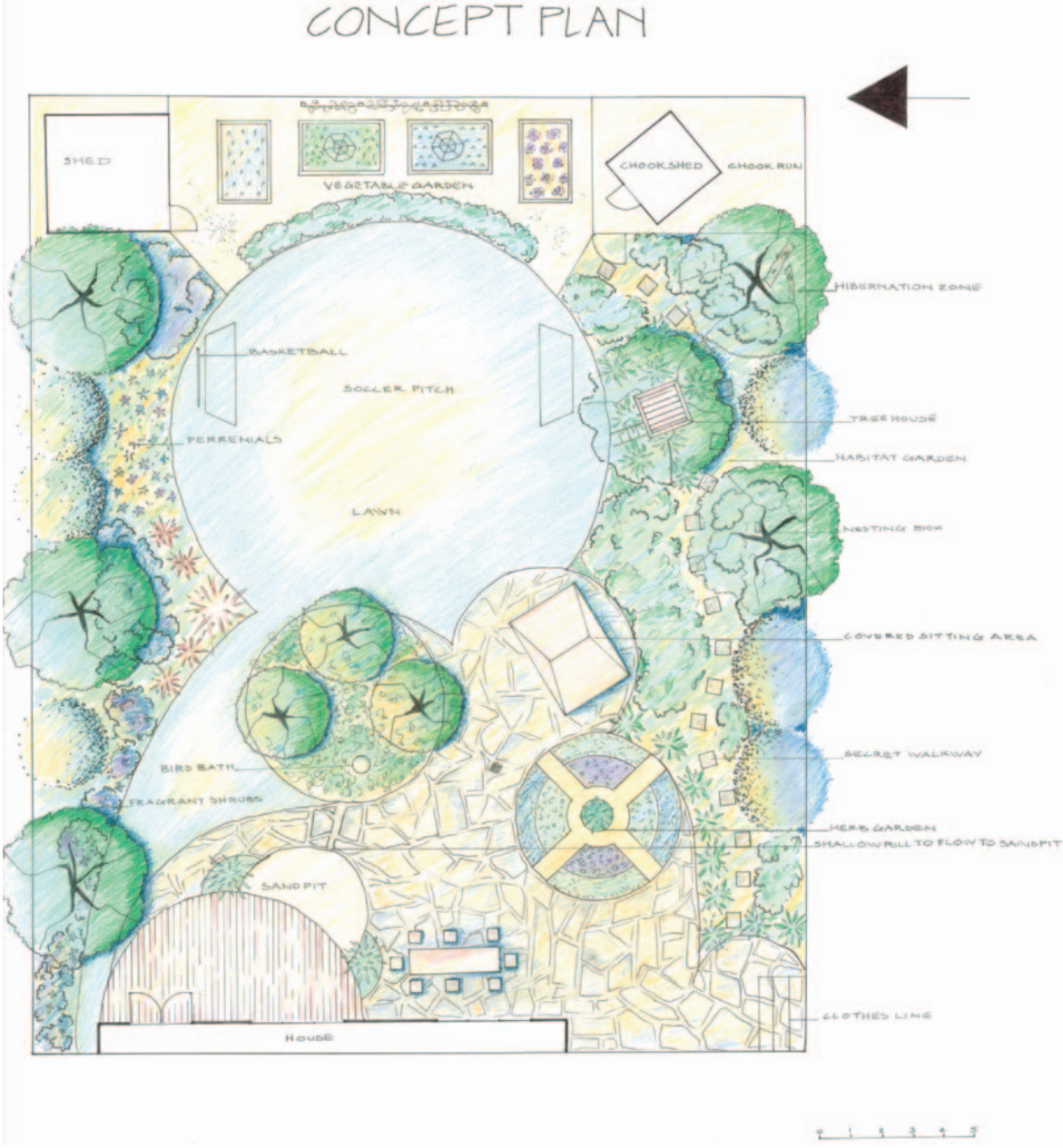
- minerals such as pebbles, gravel and crushed bricks. These are used mainly to give interesting visual effects in smaller gardens. They can be excellent at minimising water loss, but have the disadvantage that their exclusive use can impoverish the soil beneath them if fallen leaves and twigs are removed from them. Another disadvantage is that weeds that germinate amongst them are difficult to remove. It is best that they be used mainly in dry areas or under highly drought-tolerant plants such as cacti and succulents.
- woven plastic materials such as weed control mats. These can be useful for suppressing weeds. They look best when covered with a coarse organic mulch.

Never use plastic sheeting, because it will not only prevent all rainwater from reaching the soil but will also prevent vital oxygen from reaching plant roots. In summer, the high temperature under it will cook roots.

Other effects of mulches

Besides their potential to reduce water loss from soils, mulches have other worthwhile effects in our gardens. They:

- protect the soil surface from heavy rain, and so reduce the risk of crusting and erosion
- slow the flow of water across the soil and so increase the proportion moving down to where roots can use it
- change the temperature of the underlying soil. Organic mulches keep the soil cooler than it would have been without a mulch
- help control weeds (provided that the organic mulches do not themselves contain weed seeds)
- keep the fruit of crops such as strawberries and cucumbers off the soil and so clean and less liable to disease
- improve soil structure as they decompose, if they are readily decomposable organic materials
- provide nutrients as they decompose. But note the comment above about decrease in drought tolerance caused by some of these nutrients.



Therese Scales, Tikalara Designs, Victoria

NEW GARDENS AND NEW GARDENS FROM OLD

KEY POINTS

Seek help from a garden designer and a qualified landscaper

For new homes:

- **Build in water storage and recycling.**
- **Save your topsoil.**
- **Choose plants with high-quality root systems.**

Planting for success

Soil blends

Not so long ago, new gardens were usually created through the efforts of new home owners themselves. Over months and years, as they found the money and time to do it, they gradually converted their block into a garden. Gardeners also tended to do renovations themselves. Many gardeners now do not have the time or energy to undertake these major jobs. Perhaps under the influence of the 'instant makeover' television shows, many home owners now employ a landscaping contractor to do the work. But how do you choose a competent landscaper? Your Yellow Pages lists dozens to hundreds of contractors. Which ones are competent? The ones with the biggest ads or the most interesting names? Here are some suggestions.

If you are employing a garden designer, he or she will have arrangements with competent landscapers. Positive recommendation by friends who are very satisfied with the job done by a contractor is another good guide to the competence of a landscaper. If none of your friends or acquaintances has this sort of information, your next source will be one of the professional associations that cover the landscaping and urban horticulture industries. These are: the Australian Institute of Horticulture; the Australian Institute of Landscape Designers and Managers; the Landscapers Association of your state; the Nursery and Garden Industry Association of your state; the Australian Society of Garden Designers and the Australian Institute of

Landscape Architects (see Appendix 1 for a list of their websites). Associations require their members to have formal horticultural qualifications (certificate, diploma or degree) and to have proven their ability in their particular fields.

But also be aware that some competent people have chosen not to belong to an association. Rather, they rely on the considerable reputations they have earned through excellent work that is publicised by word of mouth from those who have benefited from their skills.

Whatever you do, be wary of quotations that are considerably lower than all others. You will get what you pay for. Excellent results call for the use of excellent materials that are inevitably more expensive than inferior materials. A quotation that is low because it specifies a shallower layer of or cheaper topsoil than higher quotes must be particularly suspect.

New homes: Start at the beginning

It is strongly recommended that you engage your garden designer and landscaper before a new house is started. Have them visit the bare site and let them become involved right from the start of the planning process. Then your garden will have the best chance of enhancing your home.

Build in water recycling

An essential consideration is to include in the design ways of diverting to the garden as much as possible of the free water that falls on the roof and the greywater generated within the house (see Chapter 7 for information about rainwater tanks, and Chapter 6 for greywater). The ultimate in water-proofing your home is to build in water storage under paved areas and patios (see p. 68). The landscape designer would help you design the paved and garden areas so that the runoff from the paved areas provides the greatest benefit to the garden.

Also use a design that has no small areas of garden. They are hard to water efficiently. The Sydney study quoted in Table 22 (p. 118) showed that small areas often received four times the water needed by the plants growing there.

Save the topsoil

For a new garden, wherever possible have the topsoil scraped from the area to be occupied by the building and any area that will be contaminated with mortar and concrete residues during building operations. Stockpile this soil elsewhere on the site for later re-use as topsoil. This soil will usually be much better than anything you can buy from

Being sensible: stockpiled topsoil being spread back over formed subsoil.

a landscaping supplies yard. A little modification based on a soil analysis and help from a soil scientist will give you an excellent growing medium for your plants. The cost of about $200 for the analysis and recommendations will be much less than the cost of buying in a soil blend of perhaps indifferent quality.

What must be done by your landscaper

To assist you in your interaction with your landscaper, here is a list of the sorts of things that they need to do for you:

- Clean the site. Remove debris and weeds. Remove soil that is heavily contaminated with mortar and concrete washed from builders' tools.
- Relieve, through ripping, the compaction that will have been caused by the movement of construction machinery over the soil.
- Grade and contour the area before the topsoil is spread back. If necessary, before forming the final grades, temporarily remove topsoil from any area in which it was left intact during house construction.
- Test the drainage of the formed subsoil, as shown in the box on the next page.
- Thoroughly mix any layer of coarse sandy material with the soil above and below it.
- If necessary (see p. 36), add gypsum.
- Have the stockpiled topsoil tested and amended as is indicated by the analytical results.
- Spread the amended topsoil over the contoured subsoil.

Planting trees and shrubs

The following comments apply both to new gardens and to older ones being renovated. Some simple precautions taken when planting trees and shrubs will greatly increase the chance that a plant will survive and thrive.

Tree quality

You will of course choose a tree whose top looks healthy, but there are two other factors that you must consider.

One is the quality of its trunk. The trunk should be thick and robust enough for the tree to stand erect without the aid of a stake. Trees with thin trunks that have to be staked are easily damaged during and after planting out.

An even more important factor is the quality of the root system. You cannot go around a nursery extracting semi-advanced and advanced trees from their containers to look at their roots, but you can get an idea of what they might be like. Trees grown in round plastic pots often have roots circling around the outside of the root ball. This does not happen if the inside walls of the pot have been sprayed with copper hydroxide solution. You can see this as a light green film on the inside of the pot. The copper kills the tips of roots that come into contact with it. This prevents circling of the roots, but it also forces prolific branching of roots within the root ball. See p. 109 for another option.

Time of planting

Restrictions on the use of municipal water now dictate that trees and shrubs should be planted as early as possible in the rainy

MEASURING THE INFILTRATION RATE OF A SOIL

For soil at the surface

Cut a hole of 6–7 cm diameter in the bottom of an old, thin-based, aluminium saucepan of 20–26 cm diameter (from a thrift store), as shown. Remove the handle(s). Sit the inverted saucepan on the soil surface. Place a short piece of wood on top of it and hit the wood with a hammer until the inverted saucepan has evenly penetrated about 5 cm into the soil. Invert a 2 L flagon of water into the hole in the saucepan. Much of the water will quickly flow onto the soil surface within the saucepan. If all 2 L of water flows out of the flagon, remove and refill it and again invert it into the hole in the saucepan. When the flow has stopped, quickly remove the flagon and refill it. Invert it into the hole again and record the time it takes for the whole 2 L to flow out. If this looks like taking longer than a few hours, you could remove the flagon after, say, four hours and measure the amount of water remaining in the flagon. Calculate the amount of water lost from this flagon.

Calculate the area of the base of the saucepan using the formula: 3.142 x radius in cm x radius in cm and divide the number obtained by 10 000 to get the area in square metres. Then divide the volume of water (in L) lost from the flagon by the area of the base. The number you obtain is the number of mm depth of water that soaked into the soil. Finally, divide this number by the number of hours that it took for this water to soak into the soil to give the number of mm of water that would soak into the soil in one hour.

Example

Radius: 13 cm.

Area of base: 3.142 x 13 x 13 ÷ 10 000 = 0.0531 m^2.

Volume of water lost from the second flagon: 2.0 L.

Time taken: 3.5 hours.

Therefore the infiltration rate of the soil is: 2.0 ÷ (0.0531 x 3.5) = 10.8 mm/hour.

For a deeper soil layer

Water movement into deeper subsoil can be checked by digging a hole 15 cm deep or just to the surface of any layer of clay in the subsoil. Hit the saucepan into the soil at the bottom of the hole and proceed as described above.

Interpretation guidelines are given on p. 47.

Simple equipment for measuring the infiltration rate of a soil.

The roots circling around the left root ball **must** be cut if the tree is not to end up like that on the right, which was choked to death within three years of planting.

season. That could be early to mid-autumn in southern Australia and early summer further north. Planting at these times allows rain to do most of the early watering for you. The plants' roots will have the longest time possible to establish the extensive network

A kinked root like this can jeopardise a tree's longevity. Your best guarantee that this fault is not present is to source your trees from a nursery association accredited nursery. These nurseries have quality control systems that ensure excellent root systems at every stage of production.

Advanced trees have particularly good root systems when they have been grown in Rocket®Pots and similar containers with multiple holes in their sides and bases. When roots grow into these holes, their tips die through dehydration. This death produces prolific formation of fibrous roots within the root ball.

that is essential for their survival during the first summer/dry season.

The planting hole

- Ensure that the soil surface surrounding the planting hole is free from weeds to a distance of 40–50 cm. Keeping the area weed-free and mulched is essential if early tree growth is to be rapid.
- The soil must be moist before planting.
- Dig a hole of a depth such that the top of the root ball is at the final soil height. Planting the root ball deeper than this often damages or kills young plants.
- The hole diameter at the soil surface must be at least three times that of the root ball, tapering to about twice this at the base. This allows good lateral root growth.
- Loosen the soil around the hole if it is compacted.

- A warning – if, when you are digging a planting hole you find that you are digging into very heavy clay that looks as if it drains very slowly, you must not plant without checking the infiltration rate by the method given above. Digging down a bit deeper may allow you to break through into more permeable soil below. If not, you will need to plant into soil mounded above the current soil surface, or you will need to provide drainage from each planting hole to a lower level. In any such area, citrus must always be planted on a mound.

Preparing the plant

- Remove all roots protruding through holes in the pot or tube.
- Just before planting, soak the root ball so that it becomes thoroughly wet. Include wetting agent in the water (1 mL concentrate per litre of water) so that the root ball is easy to rewet should it become dry.
- Remove the pot or tube.

Examine the outside of the root ball. If the roots generally run straight from top to bottom, or have been tip-pruned by copper or air-pruned, there is no need for further action. But for young trees, any roots that are circling around the outside of the root ball **must** be either cut through or pulled from the root ball. Use a spade to cut off the lower several centimetres of large root balls. Make several vertical cuts into the root ball to cut other circling roots further up the root ball. *Failure to remove circling roots will condemn the plant to death in three to six years, either because it is easily blown over or because the enlarged circling roots will choke it to death.*

Circling roots must be cut either with a knife or, for larger root balls, with a spade.

This attention to circling roots is less critical with shrubs than it is with trees, but major circling roots must still be cut.

Planting and after-care

- Bury a fertiliser 'pill' or two tablespoons of controlled-release fertiliser in the soil in the bottom of the planting hole. Do not do this when planting phosphorus-sensitive plants (see Phosphorus Supply on p. 26).
- If necessary, put some soil back into the hole to ensure that the top of the root ball is level with the intended soil surface.
- For small plants – those in tubes and in pots up to 20 cm – add into the hole a slurry that contains half a teaspoon of water crystals in 0.5 litre of water (soak the crystals for two hours). Water crystals will give greatest benefit in sandy soils and when frequent application of water is not possible during the first two weeks. Using water crystals is less necessary if you can apply water daily during the first two weeks after planting. Research results from

An earth basin is the best way of ensuring that a young plant gets water where it needs it. (Photo: Mt William Advanced Tree Nursery)

Florida suggest that water crystals are of little use when establishing advanced trees.

- Never add dry crystals to the backfill soil. As they expand during wetting, they can push the plant out of the soil.
- Lower the root ball into the slurry in the centre of the hole.
- Add about one-third of the soil back into the space around the root ball. Mix this soil into the water crystal slurry and gently firm it around the root ball. Add the rest of the soil and gently firm.
- Smooth the new soil surface to the same level as the top of the root ball.
- Form a basin around the planting hole so that water applied to the young tree does not run away.
- Add more water to settle the soil in around the root ball.
- Apply mulch out to at least 40–50 cm from the trunk.

Competition from weeds will ensure very slow establishment of a tree.

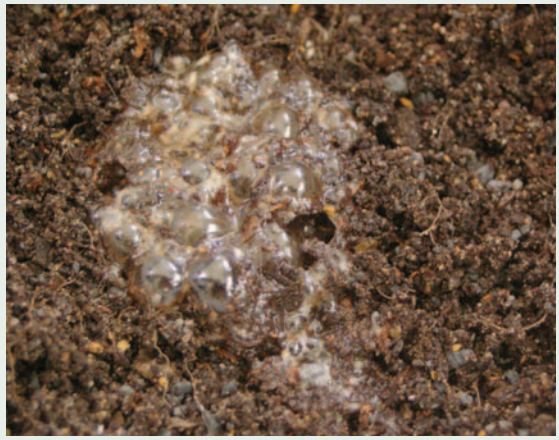
- How often you apply water depends on the weather. For small plants with water crystals in the planting hole, no extra may be needed during the rainy season. At drier times of the year and for larger plants, it is desirable to apply water every several days for the first few weeks. This water should be run directly into the planting basin, under the mulch. Water stress is the main cause of death in newly planted shrubs and trees.
- Shrubs need no staking. Nor should trees that have robust trunks, unless they are planted into a very windy situation. If staking is needed, knock two stakes into the soil outside the root ball. The trunk should be loosely held to each stake with a loop made from soft cloth.

CHOOSING A SOIL BLEND

Soil blends available from soil yards are mainly mixtures of fine sand or loamy sand and composted green organics. Some may also contain some loam or silty loam. Because these blends often contain no more than a few per cent clay, they do not develop good structure as do natural soils. As the organic matter breaks down, these blends often become water-repellent, hard-setting sandy loams. Their level of available water (Table 3) tends to be fairly low.

Ask your landscaper to choose a soil blend along the following lines:

- Ideally only buy a blend that complies with the Australian Standard for Soils for Landscaping and Garden Use. Production according to this Standard guarantees reasonable quality. If you cannot get a Standard product, you or your landscaper need to do some testing of a soil blend before purchase.
- Check its pH, to make sure that it is not too acid or too alkaline for the plants you want to grow.
- If its pH is above 8, you should try to get some idea of its total lime content. If you get very vigorous fizzing when a few drops of hydrochloric acid (pool acid) are placed on it (due to the release of carbon dioxide as the lime is dissolved by the acid), the product has a high (and perhaps unacceptable) lime content. A small amount of fizzing indicates that there is some lime present. Such a soil will be suitable for many garden situations.
- Check to see if it is sodic (see p. 36). If it is, you will need to add gypsum.
- Any blend that contains large chunks of wood or tree bark, especially if it looks raw and under-composted, should be rejected.
- Prefer a blend whose texture is in the range sandy loam to loam. The presence of some clay in the mixture will allow it in time to develop a normal soil structure. The clay will also allow better retention of humus.
- These tests will take a little time, but nowhere near as much as is needed to correct problems caused by purchase of poor soil. Be assertive: don't be talked into accepting assurances of quality at face value. Check!



Fizzing = limestone in this soil blend.

DEALING WITH TOO MUCH WATER

KEY POINTS

Protect your soil against erosion

Preventing and overcoming waterlogging

Gardeners in much of Australia might wonder what 'too much' water is, as there does not seem to be such a thing anymore. But the predictions of climate scientists are that we will have wilder swings in weather, so that there will sometimes be destructively heavy rainfall events, as there were in the Hunter Valley and East Gippsland in June 2007, even though the long-term trend is to increased dryness. In contrast, prolonged heavy rain is predicted to be more frequent in the tropics.

Bare cultivated soil plus rain = massive erosion.

You can do no more than clean up if your area is inundated, but there are a few things you can do to minimise local problems.

'Too much' water can cause problems through:

- soil erosion
- waterlogging of the soil.

Soil erosion

Erosion is the process of removal of particles from a soil surface by wind or water.

Erosion by water is prevented or reduced by:

- maintaining a full cover of plants so that the soil is protected from the pounding of raindrops and is held together by a mass of roots
- allowing water to spread in thin sheets rather than being concentrated into narrow streams of destructive force

Terracing is essential on steep slopes.

- terracing sloping sites
- protecting areas of temporarily bare soil – as when planting vegetables – with an organic mulch or with shadecloth. Water flowing from upslope should be diverted to where it can benefit plants, or to the street water table
- improving soil structure (see Chapter 3) so that water entry into the soil is rapid.

Waterlogging of the soil

A soil is said to be waterlogged if most of its pores are filled with water. There is no room for air and its vital ingredient oxygen, which is needed by all plant roots. Shortage of oxygen puts stress on plant roots. This either kills the roots directly or it makes them more susceptible to attack by pathogens such as phytophthora and pythium. The roots of plants that need excellent drainage can be killed in one day of waterlogging.

Plants announce their suffering from waterlogging by wilting, appearing stunted, looking yellower than normal and/or with the margins of the oldest leaves sometimes developing dark spots. With prolonged waterlogging there will be loss of leaves and death of root tips or whole plants.

Plants whose roots have been damaged by waterlogging may look normal enough during cool weather, but will rapidly die during the first days of heat in spring or summer, when water supply to the leaves from the almost non-existent root system will not be able to keep up with transpiration. If some of your plants die during the first warm weather, suspect that the real cause was earlier waterlogging, whose cause should be found and corrected before you replant the area.

You need to take action if your soil:

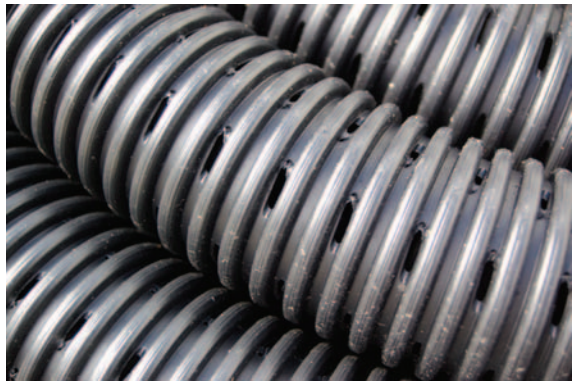
- has a continuously wet surface
- has moss and/or slimy algae growing on its surface
- kills or maims your plants in wet weather
- has a smell of rotten egg gas when you dig into it
- has free water at less than 30–40 cm below the surface.

Moss in a lawn can indicate poor drainage.

Overcoming and preventing waterlogging

Find the cause of the waterlogging. If it is due to:

- drainage from upslope, this needs to be intercepted and the water led to where it will not cause problems. A surface drain filled with gravel may be all that is needed.
- an impermeable layer in the soil, this needs to be broken through or, if this is not possible, a drainage system has to be installed. You need to consult a specialist drainage contractor for this.
- poor soil structure, this needs to be improved (see Chapter 3).
- deep heavy clay that cannot be improved, or shallow depth to bedrock, raised garden beds need to be constructed.



Plastic drainage pipe.

Succulent lawn.

LAWNS

KEY POINTS

You can still have a lawn even when water restrictions are severe
The grass must be suited to your climate and soil
For most areas, choose a warm-season grass
Prepare the soil thoroughly
When to establish a lawn
Watering lawns during drought
Effects of mowing and fertilisers on water use

Most Australian water supply authorities encourage home owners to reduce the amount of lawn they have. The main reason given is the fact that some of the water delivered to them via sprinklers is lost by evaporation as it flies through the air. Gardeners are encouraged to replace lawn with beds of other plants that can be watered via drippers. The assumption is that such beds will need less water than will a lawn. Is this factual?

One fact is that any area of **well-watered** plants – lawn or otherwise – will lose water at about the same rate under the same climatic conditions. When water supply is less, a lawn of deep-rooted, drought-tolerant grasses can have an acceptable appearance with no more water than is needed by a bed of moderately drought-tolerant shrubs (see Table 10, p. 75).

A recent study found that average water applications per square metre to garden beds in Sydney were double those to lawn areas on the same property (see Table 22). There are no figures for other urban areas, but the difference will probably be less where summers are much drier than they usually are in Sydney.

But irrespective of these facts, the use of sprinklers on lawns is now widely banned across south-eastern Australia. In some areas there is either a total ban on watering lawns or they can be watered only by bucket or watering can, or via buried drippers.

Table 22. Average application of water by 50 Sydney householders to three different types of vegetation (Maheshwari B (2006). CRC for Irrigation Futures, *Tech. Report* 01/06)

Type of vegetation	Monthly water applications by householders (L/m^2)*
Lawn	43
Exotic plants and some vegetables	87
Mainly native plants, some exotics	47

*Householders were allowed to use all types of watering systems.

Is this the end of the home lawn? Not necessarily. It would be sensible to eliminate lawn that is heavily trafficked, heavily shaded, in long narrow strips, of small area or just plain ugly. You might also find that a bed of mixed shrubs is more interesting to look at than the monoculture of a lawn. But it is possible to have some lawn for children to play on, despite water restrictions. To achieve this you must use drought-tolerant grasses that are suited to your soil and climate. With them, you can have a reasonable lawn using rain, supplemented a few times each summer with greywater or water from a tank. This chapter shows how this can be done.

This grassed area could be made into something more interesting.

Choosing the best lawn grass for your area

You will choose a grass that is adapted to your climate. The many grasses that can be used for lawns can be placed into two groups. The so-called cool-season grasses grow mainly in the cooler part of the year; warm-season grasses grow mainly or only in the warmest and hottest parts of the year.

The biggest practical difference between cool-season and warm-season grasses for drought-affected gardeners is that the warm-season grasses are much more efficient than the cool-season grasses in their use of water. The trial results in Table 23 show that, for continued satisfactory appearance, infrequently watered warm-season grasses need only half the water used by cool-season grasses.

Cool-season grasses

As the name suggests, these grasses come from areas where the climate is cool, and generally fairly moist. Most of the cool-season grasses that have traditionally been used for lawns in southern Australia have come from northern Europe and eastern North America. Here are a few facts about them.

Imported cool-season grasses

These are all C_3 grasses (see p. 17), so they are quite inefficient at using water.

- Tall fescue: Tall fescues are more drought-tolerant than are other imported cool-season grasses, but only because their roots penetrate more deeply into the soil.

Table 23. Warm-season grasses use much less water than cool-season grasses

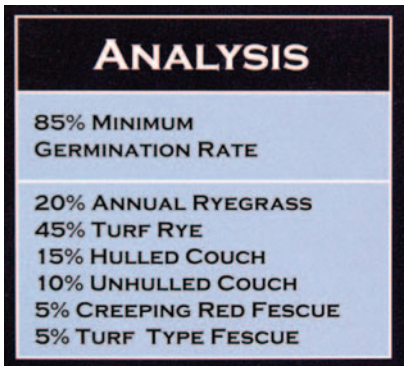
	Cool-season grasses		Warm-season grasses	
	Tall fescue	Kentucky bluegrass	Couch grass	Buffalo grass
Watering frequency	Water used, as a percentage of that used by frequently watered tall fescue			
Very frequent	100	96	69	61
Moderately frequent	90	84	57	50
Infrequent	83	78*	49	49

* All the grasses except the infrequently watered Kentucky bluegrass had a satisfactory appearance.

They are still greatly inferior to the warm-season grasses in drought tolerance.

- Kentucky bluegrass: This grass requires copious amounts of water in summer if it is to retain a good appearance.
- Perennial ryegrass: This is another heavy water user.
- Chewings fescue: This will not compete with other cool-season grasses unless soil pH is fairly low (about 5) and soil phosphorus concentration is low.
- Bentgrasses: Shallow rooting means that these grasses must be watered frequently in dry weather.

None of these grasses will produce a good lawn when water restrictions are severe. As there are better alternatives, they should no longer be used for most Australian lawns.



Plenty of water guzzlers here.

Cool-season native grasses

Research that started in the 1980s has finally led to the release of varieties of a number of Australian native grasses that produce excellent lawns in most of the urban areas of southern Australia even when they cannot be watered. Although they are C_3 grasses, they are much better able to tolerate dry conditions than are any of the imported C_3 grasses.

- **Weeping grass (*Microlaena stipoides*):** Three varieties that are suitable for urban landscapes were available at the time of writing. Two of these, Griffin and Shannon, were developed through 20 years of research at the University of New England, Armidale, in New South Wales. Griffin is fine and soft and produces an excellent lawn; Shannon is low growing and dense and is ideal for roadsides, verges and golf roughs. The third variety, Tasman, which was released in 2007, was developed from populations found in the King Lake district of Victoria by Native Seeds Pty Ltd. It may therefore be better suited to cold areas than are the other two varieties.
- **Wallaby grass (*Austrodanthonia* species):** When sown thickly, Hume Wallaby grass (*Austrodanthonia richardsonii* var. Hume)

Table 24. Tolerance of cool-season grasses to various stresses, in order of drought tolerance

Grass	Drought tolerance	Water requirement for good appearance	Salt tolerance	Shade tolerance	Frost tolerance	Wear tolerance
Weeping grass	excellent	low	medium	excellent	high	good
Wallaby grass	excellent	low	good	poor	high	fair
Tall fescue	medium	very high	medium	good	high	very good
Perennial ryegrass	fair	high	poor	medium	high	good
Fescues (other)	fair	medium	poor	poor	high	good
Kentucky bluegrass	poor	high	poor	fair	high	fair
Bentgrasses	poor	high	medium	medium	good	poor

produces a good lawn that needs virtually no maintenance other than a couple of mowings a year. It is ideal for shallow soils and where the lawn cannot be watered. Oxley (*Austrodanthonia geniculata* var. Oxley) is slow-growing and highly persistent. It is suited to both parks and lawns.

These grasses establish slowly. It is essential that you sow seed thickly and undertake a vigorous weed control program until full cover is achieved. Sowing a blend of these two grasses provides an excellent ground cover with low maintenance needs and very low water requirements. If possible, use plugs rather than seed to establish these grasses. Instant lawn of these grasses is going to be available in Victoria in early 2008.

Warm-season grasses for southern Australia

The warm-season grasses use the C_4 photosynthesis system, so they are more efficient at growing under water stress conditions than are cool-season grasses.

- **Redgrass (*Bothriochloa macra*):** The turf variety of this Australian native grass is called Bass. It grows well in infertile clay soils. Because it goes dormant in late autumn, it is best to grow it mixed with Wallaby grass. The redgrass is green from spring to autumn and the Wallaby grass is green during the cooler months. Once established, this combination will need no irrigation even where annual rainfall is only 400 mm.
- **Couch and hybrids:** Wintergreen, Santa Ana, Conquest, Windsor Green, Grand Prix and Greenlees Park have been widely used, with Wintergreen probably the most popular. All give denser lawns than does

Wintergreen.

Table 25. Other information about cool-season grasses

Grass	Preferred soil pH range	Preferred mowing height for drought tolerance (cm)	Maximum depth of root penetration (m)^	Approximate number of mowings per year	Fertiliser needs*; annual grams of nitrogen per square metre	Phosphorus requirement
Weeping grass	5–6.5	>5	1.2	6	once; 4	very low
Wallaby grass	4.5–7.5	>5	1.5	6	once; 3	very low
Tall fescue	5–8.5	5–7.5	1.1	30	monthly; 14	moderate
Perennial ryegrass	5.5–8.5	2.5–5	0.5	25	monthly; 10	moderate
Fescues (other)	4.5–6	2.5–6	0.4	20	monthly; 8	low
Kentucky bluegrass	6–7	3–7	0.4	30	monthly; 14	moderate
Bentgrasses	5.5–7	0.5–2	0.3	25	monthly; 12	moderate

^ Root penetration and total root mass decrease rapidly as mowing height is reduced.
* Monthly to every six weeks during the season of active growth, unless otherwise stated. See the end of this chapter for information on how to provide these amounts of nitrogen and other nutrients.

common (seeded) couch. The first two tend to stay green longer in winter than do other cultivars.

- **Buffalo:** Common buffalo produces a harsh-feeling lawn. There are now 10 varieties that have a softer feel. Highly popular are Sir Walter and Palmetto. They have the same water use efficiency as common buffalo.
- **Seashore paspalum (Saltwater couch):** Common names for it include Saltene and Sunturf. Velvetene is an Australian variety that has excellent turf characteristics. It is so good that it is a direct competitor to the couches and the improved Buffalo varieties in areas from the latitude of Sydney–Adelaide–Perth and north. But it is particularly useful where soils and waters are too salty for other grasses. No reduction in the quality of established Velvetene is seen even when the irrigation water has an EC of 24 dS/m (about half the saltiness of seawater). This grass prefers sandy soil with excellent drainage. Lower salinity water is needed during establishment.
- **Kikuyu:** This grass is really tough and drought-tolerant, but is so aggressive that it easily invades garden beds. Its rhizomes can easily grow under lawn edgings and paths. It is too aggressive for many gardens.
- **Zoysia:** Selections of two *Zoysia* species are available for lawns. Their deep rooting habit makes them highly tolerant of drought, but they are slow to recuperate from damage. *Zoysia tenuifolia* (Mascarene grass) has the finest leaf, but is more frost sensitive than the others. *Zoysia japonica* var. Empire and var. Empress are coarser, but more cold-tolerant. Zoysias are best suited to warm to hot and humid climates with minimal temperature fluctuation, but they grow well as far south as Sydney.
- **Siro Shadegro (*Panicum laxum*):** This is a low-growing tufted grass for sub-tropical and

Table 26. Tolerance of warm-season grasses# to various stresses, in order of drought tolerance

Grass	Drought tolerance	Water requirement for good appearance	Salt tolerance	Shade tolerance	Frost tolerance	Wear tolerance
Redgrass	excellent	low	good	excellent	fair	good
Queensland blue couch	excellent	medium	very good	poor	poor	very good
Zoysia	excellent	low	medium	good	poor	excellent
Kikuyu	excellent	high	medium	poor	poor	excellent
Couch and hybrids*	excellent to good, depending on variety	low	good	poor	fair	good
Seashore paspalum	good	medium	extreme	good	fair	very good
Buffalo	good	medium	good	excellent	poor	fair
Siro Shadegro	good	medium	low	excellent	fair	excellent
Broadleaf carpet grass	poor	high	poor	good	poor	poor

Within a species, different varieties often have different responses to various stresses.
* See www.watercorporation.com.au/w/waterwise_index.cfm for information about the different varieties.

tropical conditions, but it can grow south along the coast as far as Sydney. It grows well in heavy shade (down to 15–20% light).

Warm-season grasses for the tropics

- **Zoysia:** See details above.
- **Queensland blue couch:** It is well suited to the Gold Coast–Brisbane–Sunshine Coast region.
- **Broadleaf carpet grass:** High water requirements make it less suitable than zoysia under low-water conditions.
- **Dawson (*Bothriochloa pertusa* var. Dawson):** Low-growing, dense turf for the high rainfall tropics.

Summary for lawn grasses for southern Australia

The many different climatic niches found in southern Australia make it impossible to make firm recommendations for particular areas, but some general guidelines are:

- Only in Tasmania and at the higher elevations of the Blue Mountains, Southern Tablelands, the southern Alps and the Dandenong Ranges is it now possible to have an excellent lawn with imported cool-season grasses. But even there, restrictions on water use make it much more sensible to choose one of the more highly drought-tolerant native cool-season grasses, especially Weeping grass.
- In other cool mainland areas, the choice is between the native cool-season grasses and one of the warm-season grasses. If your microclimate is frosty and cold during the winter, the native grasses will be your best choice. For less frosty and somewhat warmer areas, the native cool-season grasses may be OK, but the warm-season grasses are likely to give better results.

Table 27. More information about warm-season grasses#

Grass	Preferred soil pH range	Preferred mowing height for drought tolerance (cm)	Maximum depth of root penetration^	Approximate number of mowings per year	Fertiliser frequency*; annual grams of nitrogen per square metre	Phosphorus requirement
Redgrass	<5.5	>3	1.8	4	once; 3	very low
Queensland blue couch	5.5–6.5	1.5–3	1.5	25	monthly; 14	moderate
Zoysia	5.5–6.5	3-5	1.0	2	twice; 5	moderate
Kikuyu	6–8	2–4	2.4	25	monthly; 14	moderate
Couch	5.5–8	1.5–3	2.4	20	monthly; 14	moderate
Saltwater paspalum	6–8.5	2-4	1.5	15	several; 5	moderate
Buffalo	6.5–8	5–7.5	1.0	20	monthly; 12	moderate
Siro Shadegro	5.5–6.5	3.5	1.0	4	once; 3	low
Broadleaf carpet grass	5–6	1.5–3	0.3	20	monthly; 8	moderate

Within species, different varieties can have different requirements.
^ Root penetration and total root mass decrease rapidly as mowing height is reduced.
* Monthly to every six weeks during the season of active growth, unless otherwise stated. See the end of this chapter for information on how to provide these amounts of nitrogen and other nutrients.

The warm-season grasses will be dormant and pale in winter and the native cool-season grasses may be a bit pale under severe summer drought conditions. Mixtures of appropriate warm and cool-season grasses will give the longest green time.

- For warmer–hotter–drier areas, only warm-season grasses should be used.

How to succeed with new and renovated lawns

Prepare the soil properly

It is essential that the roots of your chosen grass are able to penetrate deeply into the soil. This deep penetration allows them to use the greatest proportion of the rain that has soaked into the soil.

- For a lawn for a new house, you must prepare the subsoil of the area as described on p. 107. Have the top of the subsoil at such a height in relation to paths, etc. that you allow for the depth of topsoil that you want. Topsoil depth should be at least 200 mm.
- The topsoil should be of sandy loam texture for warm-season grasses, but it should have more clay (up to 20%) if you are growing native grasses.
- If the lawn is to cope with heavy use for games, the topsoil must have an infiltration rate of at least 50 mm/hr (see p. 108). This may sound high, but it will decrease as roots clog soil pores and people run and jump on the grass.
- Include fine compost in the top 100 mm of the topsoil, but not below that. Compost

Screening finished compost at Jeffries, SA.

included in deeper soil can become anaerobic and kill the grass.

- If you intend to grow a native grass or zoysia, it is essential that the topsoil have a low concentration of available phosphorus. This will favour the growth of the slower-establishing natives and zoysia over weeds.
- The topsoil is to be spread and firmed down, not compacted, and its surface formed to the final contour of the lawn.
- If you are using a poultry manure-based fertiliser, now is the time to apply it. Spread at the recommended rate and rake it into the soil. Keep applications of poultry manure products to one-third of the recommended rate when you are going to grow native grasses or zoysia.
- If you are going to install dripper lines, now is the time to do it. These should be run at 10–15 cm below the surface. They need to be no further apart than 15 cm in a sandy loam, and 20 cm in less sandy soils. Use only the special dripper line that is suitable for burying in soil.
- The top of the topsoil should be the final height if the lawn is to be established from seed, but a little lower if turf is to be used.

Remaking a lawn

Those whose lawn has thinned or died because of water restrictions, but who would still like to have a lawn, can remake the area with one of the native grasses or warm-season grasses listed above.

- First, scrape away the old turf and any thatch that has developed on the soil surface. This valuable, but probably weedy, material can be composted and used on garden beds.
- Check the infiltration rate of the remaining soil (see p. 108). Relieve any compaction, as described on p. 107.
- Check the pH of the soil and take corrective action as needed.
- Check for any layers and take remedial action, if necessary.
- Form the existing soil to the final contours.
- If needed, top up with soil of sandy loam texture.
- Incorporate fertilisers if a need has been shown by laboratory testing.
- Sow seed or lay the new turf. Instant turf of weeping grass and combined weeping grass, wallaby and redgrass turf should be available in Victoria by the time this book goes to press (check on the internet).

When to sow or plant

The best time of year for sowing/planting a lawn depends on your climate and on the type of grass to be used. A main aim is to take maximum advantage of rain during establishment.

- Cool-season grass seed should be sown in either mid-autumn or early spring. Winter

sowings take too long to germinate. No further information is given, because most lawns are now established with turf ('instant lawn').

- Cool-season grass turf can be laid out from mid-autumn to early spring, the earlier the better.
- Warm-season grass turf has traditionally been laid out from early spring to early summer in the south and throughout the wet season in the north. Trials in Melbourne have shown that early autumn turfing, when the soil is still warm, can be successful. As average temperature climbs, autumn turfing will become more viable, so long as water for establishment is available. Laying in high summer is not sensible in the south unless you can apply plenty of water during establishment.

Laying strips or squares of turf ('instant lawn')

- Water the soil a day or two before laying the turf.
- Have the turf delivered no more than one day before it is to be laid.
- Keep the exposed surfaces of the turf moist by frequent light sprinkling. Do not cover them with plastic sheeting.
- The soil surface must be lower than the surrounds of the area by the thickness of the turf.
- Spread a light dressing of lawn fertiliser over the levelled soil and rake it into the soil.
- Lay turf strips up and down sloping ground. Start at the bottom of the slope. Peg it in place on steep slopes.
- Start laying the turf along a straight edge of the area. Roll out the strip and pull it hard up against the edge.
- Lightly tamp the turf with a broad, flat tool made from thick boards and a pole.
- Any hollows should be filled by spreading more soil under the turf; any humps should be removed from underneath the turf.
- Stand on a wide plank placed on the first strip when laying the next strip.
- Stagger joints in the same way as when bricks are being laid.
- Do not have short pieces of turf at the ends of rows of turf. Rather, have full pieces at each end of a row and any short piece needed towards the middle.
- Trim the turf with a sharp kitchen knife when it has to be fitted around curves or cut to fill a gap.
- Water the turf within an hour of laying in warm weather, sooner in hot.

Frequent watering in the first week after laying will prevent this.

- Water daily to several times each day for the first two weeks in warm to hot weather, less frequently in cool.

Early care of new lawns

- For all grasses EXCEPT native grasses and zoysia, apply lawn fertiliser with an NPK composition of something like 10-2-6 at a rate of about 20 g per square metre (g/m^2) each two weeks to seedling lawns until coverage is complete. Then reduce the frequency to monthly or every six weeks. One early application may be all that instant turf needs before you start the regular program.
- Seedlings that do not respond to the first couple of fertiliser applications, and look dull green to yellow with purple colours, are probably suffering from phosphorus deficiency, due to there being little in the sandy soil blend you have used. When this happens, switch to a general garden fertiliser with a composition of something like 10-4-6 until the grass greens up and starts to grow. An alternative is to apply single superphosphate at a rate of 25 g/m^2 and continue with the 10-2-6. Reduce the frequency once you have full cover.
- If native grasses or zoysia look pale and are not growing well, apply a mixture of urea and potassium sulphate (1:1) at 5 g/m^2. It is particularly important that you do not apply phosphorus to native grasses. Doing so will just encourage weeds to out-compete them.
- Mow as soon as is possible – probably about one month after sowing seed and one week after laying turf. Mowing will encourage the grass to thicken up.
- Once you have full cover, give the soil a thorough and deep soaking if rain has not done this for you. Your aim is to make sure that the subsoil is moist.
- Then increase the time between waterings, so as to encourage the roots to grow deeply into the soil.
- All this effort will be wasted if you do not regularly wander over your lawn and remove or selectively spray weeds while they are young. Letting them go to seed or allowing such nasties as creeping oxalis to spread unchecked will soon give you a weed patch. A few minutes each couple of weeks will keep your lawn looking attractive.

Watering lawns

Much more information about watering is given in Chapters 7 and 8. Here are just a few important points for lawns.

- If a ban on the use of sprinklers means that your established lawn can only be watered by hand, it may be better not to water it at all. Let it go brown. If rain is not too many months in coming, the warm-season grasses and native grasses will shut down, but not die. Prolonged drought will thin out or kill imported cool-season grasses, so giving you an opportunity to grow something tougher.
- In southern Australia, if you are able to divert water from a rainwater tank or the laundry, you should be able to keep a lawn of grasses suited to the area going with perhaps two deep soaks (each of 50–100 mm) during summer.
- Where watering is possible, it must be infrequent and deep. That generally

means no more often than once a month. This encourages deep root penetration and maximum drought tolerance. It also discourages the growth of shallow-rooted weeds.

Mowing

A fundamental rule for lawns is that the grass must be mown frequently enough so that you never remove more than one-third of the green leaf area at any one mowing. That could mean twice each week at the peak of the growing season to less than monthly when there is little growth. The sudden removal of leaves caused by mowing inevitably reduces root growth for a while. A cycle of rank growth and scalped grass caused by infrequent mowing will severely damage roots. The weakened plants with their shallow roots have a poor ability to withstand drought or other stress. Soon all you will have is a weed patch.

Another fundamental rule is that to maximise depth of rooting, and hence maximise the grass's access to water, you must cut the grass as high as possible. This might sound upsidedown, but think of it this way: root growth depends on photosynthesis in leaves. Tall-cut grass has a much larger leaf area than does grass cut as short as bowling green grass, so it is able to support a much deeper root system. It will of course transpire more water than will shorter grass, but this is more than compensated for by its ability to remove water from a larger volume of soil. This applies particularly to cool-season grasses. The more horizontal growth habit of the lawn types of warm-season grasses such as couch means that this effect is smaller with them. When cut relatively short they can still have a deep root system. Follow the guidelines in Tables 25 and 27.

Scalping: on the road to a weed patch.

- For cool-season grasses, keep mowing height moderately high during spring, raise it during summer and gradually lower it during autumn. For warm-season grasses, mowing height can be high during spring, gradually lowered during summer and then raised again during autumn to promote winter hardiness.
- If you don't like mowing, and you have difficulty finding the cash for a contractor to do it as frequently as is desirable, you need to look at Tables 25 and 27. There, you will see listed a number of grasses that need far fewer mowings than do many of the grasses that are commonly grown. Choose one of them for a new lawn or use them when you remake your existing lawn.
- Until the cut ends of leaves left by mowing seal over, they lose water at a faster rate than does the rest of the leaf. This loss is greater through ragged cuts left by blunt mower blades than through the clean cuts

from sharp blades. By regularly sharpening mower blades, you make a further small contribution to the well-being of your lawn.

- Don't mow on days when the temperature is likely to exceed 35°C.
- Don't mow immediately after watering or substantial rain. Doing so may compact the soil.

Dealing with thatch

Thatch is a layer of dead and living shoots, stems and roots that develops on the surface of the soil below the leaves of lawn grasses. A thin layer of thatch is desirable because it gives spring to a lawn and cushions the soil against compaction. A thick layer is undesirable because it can reduce water penetration into the soil, increase disease problems and allow scalping of the grass. It often becomes water repellent. The grass will then not get the full benefit of rain as some of the rain will either run off the lawn before it can soak through the thatch, or it will soak in unevenly and give the lawn a patchy appearance. Water repellence is overcome by applying a wetting agent. To minimise thatch development, do not apply more fertiliser than is given below.

Thatch decomposes naturally when moist and not too acidic. A common cause of slow decomposition is that the thatch has become too acidic from fertiliser applications. Check the pH of the thatch layer in your lawn. If it is below 6, applying lime at a rate of 0.5 to 1 kg/m^2 will speed up decomposition. Applying sugar (about 50 g/m^2) with the wetting agent and lime will further speed thatch decomposition.

Compaction

Clay soils under lawns can be severely compacted by heavy use for games or general traffic. The resulting poor drainage can seriously reduce root growth and lead to a rapid decline in lawn quality. The compaction may be temporarily relieved through coring. Remove the core material and fill the holes with sandy loam. Long-term care of heavily used lawns is easiest if the uppermost 200 mm of the soil is a sandy loam.

Fertilising lawns

Water use is minimised if you apply only the amount of fertiliser needed to keep the lawn just growing. The grass is then at its most efficient at extracting water from the soil, but is not losing excessive amounts by having a huge amount of leaf. Excessive use of fertiliser nitrogen produces heavy leaf growth and a marked decrease in root growth. So not only does heavy fertiliser use increase water use (and thatch production and mowing frequency), it also reduces the ability of the grass to reach water in the soil. Water a lawn thoroughly before applying soluble solid fertilisers. Allow the leaves to

A mulching mower.

dry off, apply the fertiliser and then WATER AGAIN IMMEDIATELY TO PREVENT LEAF BURN.

Do not fertilise grass that you cannot water or which is dormant.

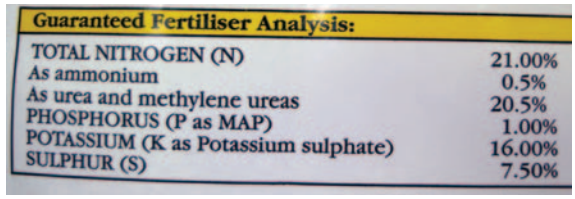
Here are two strategies for fertilising lawns:

Lawn fertilising at its easiest

- Use a mulching mower so that losses of nutrients from the lawn are minimal.
- For soils that are amply supplied with phosphorus, annually, at the start of the growing season, for all grasses except the native grasses and zoysia, apply a synthetic slow-release source of nitrogen (Blue Chip or IBDU) at a rate of 30–40 g per square metre; apply potassium sulphate at 15 g per square metre once a year just before the season of slowest grass growth.
- For native grasses, the application rates are no more than one-third of the above and for zoysia and Seashore paspalum about half.

Lawn fertilising with much more effort

- Buy a fertiliser specially formulated for lawns. The fertiliser will have an NPK content of something like 10-2-6.
- Apply the fertiliser at a low rate at the beginning of the main growing season, but not when it is too cold for the grass to grow. A typical rate is 20 g/m^2. Half this rate could give satisfactory results if clippings are not removed.



Guaranteed Fertiliser Analysis:	
TOTAL NITROGEN (N)	21.00%
As ammonium	0.5%
As urea and methylene ureas	20.5%
PHOSPHORUS (P as MAP)	1.00%
POTASSIUM (K as Potassium sulphate)	16.00%
SULPHUR (S)	7.50%

This lawn fertiliser contains methylene ureas – a slow-release source of nitrogen. It is an alternative to the 'easiest' fertilising method when some extra phosphorus is also needed.

- Note that the rate recommended here may be lower than that recommended on the bag. There is little point in adding large amounts of fertiliser that will give large amounts of growth that will have to be removed by mowing.
- Continue to apply the fertiliser at a low rate every four to six weeks of growing season. Change the rate and/or amount depending on grass response.
- Towards the middle of autumn in southern Australia, replace half of your application with an equal weight of potassium sulphate. The extra potassium will toughen up the grass.

… and no evaporative cooling.

Earthenware ‘pots’ in the desert.

WATER FOR PLANTS IN POTS

KEY POINTS

- Basics of potting mixes
- Balance between air and water in potting mixes
- Over-watering and its prevention
- Using additives to extend the time between waterings
- Wetting agents and their use
- How often to water
- Providing water via hoses, drippers and by sub-irrigation

A plant in garden soil can send its roots in all directions to the limits of its genetic capabilities. When it tries to do that in a pot, its roots soon hit an impenetrable barrier. The amount of water available to a plant in a container is therefore strictly limited to something less than the volume of the container. You have to repeatedly top up that volume if you want the plant to remain alive. If you find this a hassle, it is easy to automate the watering.

A first requirement is that you understand a little about the basics of potting mixes and their properties.

Potting mixes

All potting mixes sold in Australia are now mixtures of organic materials, sometimes with a small amount of sand, but no natural soil. The main organic material used is composted pine bark, but there can be varying amounts of composted sawdust, composted green organics, coir fibre dust, natural peat, animal manures and so on.

Grafted darwinias in full flower.

Scaevola aemula makes an attractive addition to any patio. (Photo: Rodger Elliot)

Humus produced by the decomposition of these organic materials takes the place of the clay of soils. Cheaper mixes tend to have higher proportions of sawdust and other wood wastes. Quality varies considerably. The best potting mixes conform to one of the two grades of the Australian Standard for Potting Mixes (see box).

A potted agave would look good in any courtyard.

Australian Standard mixes carry the StandardMark on their bags. It is recommended that you buy only those potting mixes whose packs carry this StandardMark. This Mark guarantees that the mix in the pack has been produced with properties that conform to the Australian Standard for Potting Mixes. That guarantee is backed by independent checking of the quality control records at the factory and of independent analysis of random samples. Feedback from the analyses ensures that quality is maintained from batch to batch.

What the Standard does not cover

The Standard does not cover anything that you do to the mix before you use it, nor does it compensate for poor growth that is due to poor environmental conditions around a potted plant. Keep in mind that:

- All plants in all potting mixes eventually need more fertiliser than is in the potting mix when you buy it.
- Over some months in pots or in the bag, even mixes that were manufactured according to the Standard may become more difficult to rewet if they get dry, no matter how excellent rewetting was when you bought the mix. That is a natural effect of continuing activity by microbes living in the mix. You will then need to improve wettability by adding a wetting agent.
- Soluble nitrogen in Premium mixes will be steadily used by microbes so, after a couple of months of storage, you will still need to add fertiliser at potting.

AUSTRALIAN STANDARD POTTING MIXES

Australian Standard AS 3743–2003 (and updates) requires that a potting mix that is claimed to conform with it must have physical and chemical properties that ensure good plant growth. All mixes must:

- drain well; a minimum air-filled porosity of 13% (see later in this chapter) is specified for general-purpose mixes
- be easy to rewet should they dry out in the first couple of months of use
- contain all trace elements in amounts that will be adequate for plants for one year
- contain adequate initial amounts of the nutrients potassium, calcium, magnesium and sulphur that are in balance with one another
- contain a level of phosphorus that is suited to the plants to be grown. Mixes for phosphorus-sensitive plants have lower concentrations of phosphorus than do general-purpose mixes
- have a suitable pH. General-purpose mixes must have a pH in the range 5.3–6.5; the pH of mixes for acid-loving plants is to be in the range 4.8–5.8.

Standard Premium mixes must also have a supply of nitrogen sufficient to give at least one month of good plant growth even when other fertiliser is not used. In other words, you can transplant a small plant into newly bought Premium mix straight from the bag and expect the plant to grow well for at least a month before you need to apply fertiliser.

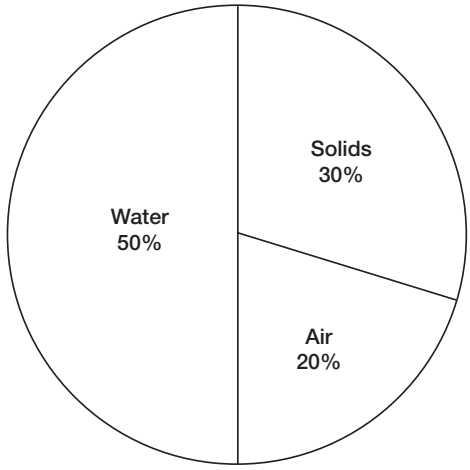
The costs of testing and maintaining the high quality of these genuinely Premium mixes means that they cost more than do other mixes. You will usually find the response in your plants is well worth this extra cost. After all, the cost of the potting mix is usually small compared with the cost of the plant you put in it.

Standard Regular mixes are not required to have soluble nitrogen in them when sold. It is essential with them that you use a fertiliser at potting. Either include a controlled-release fertiliser in the mix before potting or start a soluble fertiliser program immediately after potting. You will usually find that you will use less fertiliser with these Regular mixes than you need to use with non-Standard mixes.

The cheapest way of ensuring that your plants get what they need is to use a Standard Regular mix that has the right air-filled porosity for your plants and, just before potting, add a combination of slow-release fertiliser (e.g. Nitrophoska Slow Release) (1 g/L) and controlled-release fertiliser (3–6 g/L), plus wetting agent.

Non-Standard mixes

You take pot luck with potting mixes that make no claim for compliance with the Australian Standard. Some mixes may produce satisfactory results, but spot checking has shown that they vary enormously in quality. It is impossible to tell whether the contents of a particular bag will or will not give good growth, even with the best of fertilisers. Any manufacturers who claim to have excellent products will long ago have backed these claims by testing, and will be producing according to the Standard.



Approximate proportions of solids, water and air in a general-purpose potting mix.

Potting mix properties

A quick sketch of the main properties of potting mixes will give you a solid basis for understanding how to manage your plants in them.

Air and water

A potting mix is composed of particles of various sizes. These particles provide the structure of a potting mix in the same way that aggregates and sand grains give soils their structure. Potting mix producers screen raw materials such as pine bark to various particle size grades and then re-combine these grades so as to give each product the required structure. For example, a mixture for germinating seed needs to be quite fine, so only particles smaller than about 5 mm are used. A potting mix for general use will be coarser, with particles up to perhaps 12 mm across. Orchid bark typically has all particles larger than about 10 mm. The skill required by a potting mix producer is to consistently produce a product that has the same range of particle sizes.

Particle size range determines how the mix behaves towards water and air.

- Think of two pots, one filled with fine beach sand, the other with coarse gravel. Obviously, the spaces (pores) between particles in the sand are much smaller than those in the gravel. The gravel is more 'open' than the sand.
- Now think of watering the two pots. After drainage has stopped, the sand will be saturated almost to the top of the pot. In fact, knocking the pot will probably cause a slurry of sand to run from the drainage holes. Few pores, if any, contain air. On the other hand, the only water held by the gravel will be a film on the surfaces of the particles and in the narrowest parts of pores where particles touch. The rest of the pores contain air.
- The sand will contain too little oxygen for the roots of most plants; the gravel will not

Table 28. Desirable air-filled porosity of potting mixes for different situations, as measured by the Standard Method

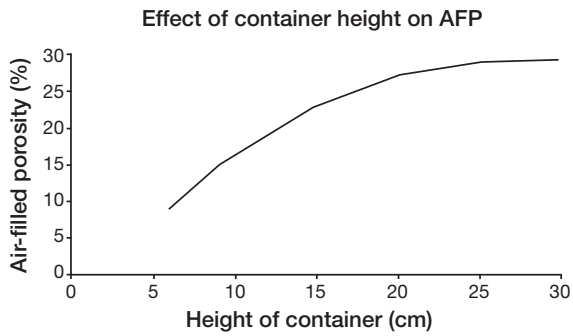
Situation	Desirable air-filled porosity (% volume)	Approximate water-holding capacity (% volume)
Seedling native plants in tubes	9–12 (least open)	60+
Seed-raising mix for punnets	10–15	60+
Mix for larger outdoor pots	10–15	50–60
Ferns	12–18	50–60
General indoor plants	15–25	45–60
Propagation mix	20–25	30–40
Cymbidium orchids	20–30	30–50
Epiphytic orchids	35–50 (most open)	<25

hold enough water for any plants other than epiphytic plants such as tropical orchids.

Potting mixes must have a better balance of air and water than this. Manufacturers give them this balance by carefully adjusting the proportions of particles of different sizes. Two terms are used to describe this balance between air and water. One is '**air-filled porosity' (AFP)**, which is the percentage of the volume of a potting mix in a container that is air space when it has just finished draining following watering. In other words, it is the minimum percentage of air that will be in the mix. Evaporation and transpiration steadily remove water from the mix and so steadily increase the proportion of the mix that is air. The other term is '**water-holding capacity'**. It is the proportion of the mix that is water when drainage has just stopped. It is a rather crude measure, because not all of this water is available to plants. But knowing the water-holding capacity of mixes is useful for comparing them (see Chapter 14 for simple methods that you can use to determine the AFP and water-holding capacity of a potting mix).

Effect of pot depth on air-filled porosity

Potting mix in a pot behaves in much the same way as a saturated towel on a clothes line. Just after drainage has stopped, the bottom part of the towel is still saturated with water. Above the saturated part is a very wet zone, with water content then grading to the lowest level at the top of the towel. A bath towel and a hand towel of the same thickness hanging side by side on the clothes line will each be seen to have the same depth of saturated and very wet zone. But the shorter height of the hand towel will mean that its average wetness will be greater than that of the bath towel.



As pot height increases, the proportion of air in a mix increases.

So it is with potting mix in pots. The depth of saturated and very wet mix is the same no matter what the total height of the mix. For the one mix, the average wetness is greater when it is in a shallow pot than when it is in a tall pot. Conversely, the proportion of air in a just-drained mix will be less when it is in a shallow pot than when the same mix is in a tall pot. A potting mix in which the balance between air and water is good in a shallow seedling punnet may contain so little water in a tall pot that frequent watering of plants will be necessary. On the other hand, a mix that has excellent properties in a tall pot will probably contain too little air when placed in a squat pot.

Changing the width of a container or the general shape of its sides has no effect on the proportions of air and water in potting mix in it. Of course as pot size increases, the total amount of water available to a plant in it increases.

Balance between oxygen and water

The Australian Standard for Potting Mixes requires that conforming mixes have an air-filled porosity of at least 13%. This is really an absolute minimum. A mix with this or lower air-filled porosity will have a high ability to hold water, but there is a danger that, with frequent watering, roots in the bottom of the container will be constantly wet and will become stressed through lack of oxygen. Stressed roots are easily attacked by any pathogens in the mix. They rot and soon the whole plant is dead. Gardening books refer to this as 'over-watering'.

The way to prevent over-watering even when you water frequently, is to use a potting mix that has an air-filled porosity in the range 18 to 25%. Roots in a mix of this openness will rarely suffer from lack of oxygen. The downside of such a mix is that it holds less water than a tighter mix, so you will need to water more frequently.

You have a choice:

- Use a mix with low air-filled porosity and be very careful about how often you apply more water, or,
- Use a more open mix, water as frequently as you like and forget about creating problems for your plants from over-watering.

Here are some guidelines for choosing potting mixes:

- For shallow containers – squat pots – choose a mix with an air-filled porosity at the upper end of the 20–25% range. This does not apply to bonsai.
- For plastic and glazed ceramic containers of 1 L to about 5 L capacity, choose a mix with an air-filled porosity at the lower end of the 20–25% range. For similar pots with capacities up to about 10 L, choose a mix with an air-filled porosity in the 15–20% range.
- For tubs and deep (deeper than about 30 cm) planter boxes, the potting mix can have an air-filled porosity of around 10%. It can contain fine sand or even 20–30% loamy soil.
- Hanging baskets lined with natural coconut fibre or a porous synthetic material and unglazed ceramic pots lose water through their sides. This evaporation

is useful, even essential, for plant survival during summer as it cools the plant's roots. But of course the potting mix does dry out faster than if it were in plastic pots of similar volume. This more rapid drying allows you to use a fairly tight mix in them, say with an air-filled porosity of around 15% where evaporation rates are fairly high. If you use a more open mix your plants may suffer from frequent dehydration.

- Some books recommend painting the insides of unglazed ceramic pots to stop evaporation through their sides. This is silly. It is more sensible to choose a potting mix that allows you to use evaporation to aid plant survival in summer.

Changing the air-filled porosity of a mix

Unfortunately, the bags in which potting mixes are sold do not state the air-filled porosity range of the contents. If it is a Standard mix, you know that its air-filled porosity will be at least 13%, but that is all. Really all you can do is to buy a few different brands, check the air-filled porosity yourself (see Chapter 14) and then stick with the one that best suits your conditions. Once you have taken a few mixes through the test, you will get to know the feel of mixes of different porosities and so more quickly choose on the basis of initial feel. If you still can't find a suitable mix, you can modify one as follows:

- To increase the air-filled porosity of a mix you must add something coarser to it. The amount needed depends on the fineness of the original mix and the degree of change needed. Often the addition of about one-third by volume is a useful starting point.
- The coarse material that is easiest to obtain is usually orchid mix. Other coarse materials include very coarse sharp sand, 3 mm gravel (including scoria, but absolutely not crushed limestone or marble, because they can raise mix pH high enough to cause trace element deficiencies) and coarse bark.
- You can reduce air-filled porosity by adding coir fibre dust (Cocopeat, etc.) or fine sand. Start with a 10% (by volume) addition and check air-filled porosity before adding more.
- If your main aim is to increase water-holding capacity, coir fibre dust is the best material to use. Add 10 to 20% by volume.
- When you are able to modify a mix as you wish, you can make it as open or 'tight' as you want. The choice is yours!

Composted pine bark of different gradings.

WATER CRYSTALS AND POTTING MIXES

While the various water crystals can hold up to 300 times their weight of distilled water (see p. 52), when they are included in potting mixes, the actual amount held is much less. This is because of the effect of fertiliser salts, physical constraints on expansion of the crystals in the mix and their slow rate of water absorption compared with the time taken to apply water. These effects mean that even the best water crystals hold only about 20–40 g water per dry gram when incorporated into potting mixes (Table 29).

In addition, not all of the water in the crystals can be used by plants. Incomplete contact between crystals and surrounding particles as the mix dries means that there is limited transmission of water from them to distant roots. This effect will be greatest immediately after potting a plant and will decrease as its roots grow around and through the wet crystals. But even then, not all of the water in crystals can be extracted by plants before they wilt.

All this means that in contrast to the benefits seen in sandy soils (see p. 53), the benefits of water crystals in potting mixes are rather smaller than can be obtained by including 10–20% coir fibre dust in the mix.

Table 29. Effect of four brands of water crystals on extra water held by a potting mix when they were added at a rate of 1 g dry/L mix

	Potting mix of 16% AFP		Potting mix of 33% AFP	
Treatment	Extra water held by mix (g/L)	Time to wilting (hours)	Extra water held by mix (g/L)	Time to wilting (hours)
Control	–	61	–	55
Water crystal 1	6	59	20	60*
Water crystal 2	7	61	34	60*
Water crystal 3	14	60	35	62*
Water crystal 4	24	64*	29	61*

* Significantly different from time-to-wilting of control plants.

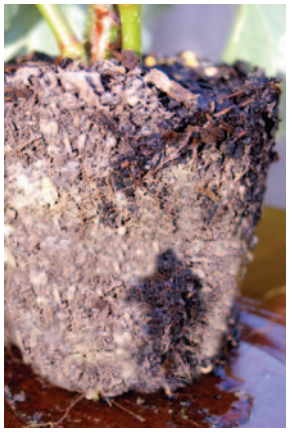
Dealing with non-wetting mixes

Organic potting mixes are often difficult to rewet if they dry out either before potting or when in pots. Suspect that the mix in a pot has become non-wetting if water pours rapidly out of the drainage holes at the start of watering. The water has run down the outside of the root ball or through the larger channels in the mix and has hardly made it any wetter than before watering. Scratch below the surface of the mix after watering. Dryness indicates a non-wetting problem.

Difficulty in wetting is caused by the presence of waxy materials produced by fungi on the surfaces of particles. Dry mix can be rewet by dunking the pot into a bucket of water for 10 minutes each time it dries out. This is of course a bit difficult with 30 litre tubs. Fortunately, there is an alternative to dunking.

Wetting agents

The simplest way of ensuring quick rewetting of potting mixes is through the use of wetting



Most of a water-repellent potting mix is not made wet during normal watering.

agents. A wetting agent is really just a special type of detergent that is only slowly broken down by microbes. The wetting agent allows water to spread more easily across the surfaces of particles in the potting mix. When applied at the recommended rate, the best remain effective for four to five months.

A common question is*: 'Why can't I use cheap dishwashing liquid rather than those expensive wetting agents?'* The answer is that you can use a dishwashing liquid if you have nothing better. Add 2–4 mL to each litre of water used for dunking or pouring onto the dry pots. But you also need to know that the effect of dishwashing detergents disappears within a week of addition, because the detergents in dishwashing liquids are required by law to be biodegradable: they are designed to be broken down in less than a week by microbes in sewage treatment plants.

Wetting agents come in two forms:

1. A thick liquid. This has to be diluted with water before it is added to a potting mix.
2. A granular solid, usually a calcined clay or coir fibre dust. These products are just mixtures of the liquid wetting agent with the solids. They generally contain 10 to 15% of the liquid wetting agent. Granular wetting agents can be more convenient to use than the liquids.

Bentonite clay is also sold as a wetting agent. While it may be beneficial in sandy soils, research has shown that it does not overcome water repellency when added to potting mixes.

Ways of adding wetting agents to mix in containers

Method 1

1. Make up a solution of the wetting agent by adding 1 mL of liquid concentrate to each litre of water.
2. Dunk each pot into the solution until bubbling has stopped, indicating that the whole of the potting mix is wet.
3. Remove and allow the excess to drain back into the dunking solution.

Applying a wetting agent solution.

Method 2

1. Make up a solution of wetting agent by adding 1.5 mL concentrate to each litre of water.
2. With a watering can, slowly pour the solution all over the surface of the mix until there is some drainage from the pot.

Method 3

1. Sprinkle granular wetting agent onto the surface of the mix, at the recommended rate.
2. Water lightly to allow release of the wetting agent from the granules.
3. Water a little more heavily next day to flush the wetting agent into the mix.

Note: All wetting agents available in Australia will not harm plants if they are used at the recommended rate. But several of them have been found to reduce plant growth when they are applied at two or more times the recommended rate. Do not go above the recommended strength or rate and do not apply them more frequently than once every three months.

Matching watering with mix, plant and environment

Table 30 gives an idea of the effects of indoor environment on losses of water from potted plants. The main point to be gleaned from the table is that decreasing humidity, combined with increasing draughtiness and air temperature, dramatically increases losses of water from pots.

Thus, a blast of warm, dry air from an air conditioner in winter will cause plants to lose water rapidly. A plant in a cool bathroom will have a very low rate of water loss.

Table 30. Rate of evaporation of water indoors, as affected by air temperature, air humidity and rate of air movement. The figures are mm of water evaporating per 24 hours from a dish of water

Relative humidity of the air	Almost still air; mm water lost		One metre in front of a typical air conditioner; mm water lost	
	18°C	26°C	18°C	26°C
90% (very humid)	1	2	3	5
50%	5	10	18	33
10% (very dry)	10	19	22	48

Other factors affecting rate of water loss are:

- Plant size: the larger the plant, the more rapid the loss of water.
- Pot size: for a given size of plant, watering frequency can decrease as pot size increases.
- Type of plant: many thin-leaved plants from tropical lowlands seem unable to slow their rate of water loss as the growing medium dries out; they lose water until they are totally wilted. Plants with variegated leaves lose water more slowly than all-green plants of the same size.

Crocking

Crocking is the practice of placing a layer of gravel or broken ceramic pots in the bottoms of pots 'to improve drainage'. As crocks reduce the height of the potting mix, they increase the average wetness of the mix above it. Crocking therefore increases the risk of

damaging plants by over-watering. Commercial nurseries worldwide annually produce hundreds of millions of potted plants without crocking. Using a potting mix with a suitably high air-filled porosity is your best guarantee of not harming pot plants by over-watering.

One place where crocking is useful is in the bottoms of pots without holes. The main such pots are terrariums. The spaces in the gravel act as a reservoir for any water added in excess of the holding ability of the mix. If the gravel were not there, the extra water would be retained in the mix, making it too wet. Crocking may also be desirable in terracotta pots that have one relatively small drainage hole which is easily blocked.

Reducing evaporation from the mix

You can increase the time between waterings by mulching the surface of the mix. Use any coarse, decorative material such as bark nuggets, water-worn pebbles, coloured wood chips, scoria or gravel (not marble or limestone, because they will raise mix pH high enough to cause trace element deficiencies). The depth need be no more than one or two particle thicknesses. A less decorative alternative is to place a disc of coir matting on the surface of the mix.

Deciding when to water plants in containers

For pots large and small

- A droopy plant is telling you what you should have done some time ago.
- You can quickly check small pots by lifting them.
- Look at the surface of the mix in the pot. There is no need to water if it is obviously moist.
- Investigate further if the mix looks dry or is only slightly moist. Dig down a couple of centimetres. Dry mix indicates a need to water. Moist mix probably means that you can wait another day.
- Another check for large pots is to tap the side of the pot. A hollow sound probably indicates a need to water.
- Feel the mix at a drainage hole. If it's wet, don't water.

For hanging baskets

- Wire baskets that are lined with coconut fibre, bark or synthetic materials should be watered if the bottom of the basket feels dry.
- Test plastic hanging pots as given above for pots.

Less satisfactory methods

- Daily watering may be satisfactory in summer for outdoor plants in open mixes, but in cool weather and for plants in less open mixes, a constantly wet mix can lead to rotting of roots.
- Moisture probes are inaccurate and can be very misleading. They usually still read 'wet' when the mix is too dry for good growth of plants. The amount of fertiliser in the mix affects the reading.
- Never water a wilted plant if the mix is still wet. The wilting probably means that the plant's roots have been damaged. Withholding water may enable the plant to recover.

Amount of water to apply

- Don't ever just sprinkle a bit of water onto the surface of the mix. Rather, add enough water so that a little runs out the drainage holes. If your water is saline, add enough so that an amount equal to about 10% of pot volume runs out the bottom. Excessive drainage causes excessive loss of nutrients.
- The drainage water which is caught in a saucer under pots indoors can be left there for later use by the plant. If the potting mix is open enough, the water in the saucer will not harm plant roots.
- The more salty your water, the more frequently you must flush the pot to remove excess salts. Frequency of flushing can range from monthly to annual.

Temperature in pots

The natural situation for most plants is for their roots to be in an environment of more even temperature – and during the day, lower temperature – than that around their tops. The situation can be quite different in pots.

- In the shade, the temperature of the outer part of mix in a plastic pot will be about the same as that of the surrounding air. Up to an air temperature of about 30°C, the roots of most plants likely to be grown in pots will not be harmed. In fact, temperatures in the 20s give maximum growth rates for many plants.
- But as mix temperature goes into the 30s, roots will be increasingly stressed. The roots of many plants are killed by several hours of temperatures over 40°C in the mix.

Knowing the temperature of potting mix in a pot can be very informative.

- Sun shining directly onto the outsides of pots will heat the mix inside. Even on a mild day (22°C) the temperature on the sunny side of black plastic pots can exceed 40°C; on a hot day, the temperature can quickly exceed 50°C. Temperatures rise highest in dark pots on light backgrounds, so where summers are hot, prefer light-coloured pots. Always shade plastic pots on warm-to-hot days.
- As root temperature increases, both evaporation of water from the mix and transpiration from plants increase rapidly. Watering must be more frequent.
- Evaporation of water from the sides of wire hanging baskets and unglazed terracotta pots will cool the mix inside by several degrees. This cannot happen through the sides of plastic or glazed (or painted) ceramic pots. Plants tend to survive best in hot weather in baskets and unglazed pots – *as long as you water often enough to make up for the more rapid loss of water from them.*

- Therefore, if you live in an area where summer temperatures often exceed 35°C, ignore any advice to seal the inside surfaces of unglazed ceramic pots.
- Many indoor plants, being from the tropics, do not like low temperatures. Daytime temperatures should be at least 15°C. Night temperatures as low as 5°C are tolerated by some species but not others. Sudden changes in temperature should be avoided: in winter, warm irrigation water to about 20°C.
- Tropical plants being grown in cool areas will have warmer roots if they are grown in plastic pots rather than in terracotta pots.

Ways of watering plants in containers

Water is mainly applied to the surface of the potting mix in containers, but it can also be applied through the drainage holes.

Water to the potting mix surface

If you have large groups of plants in containers, you could set up a fixed sprinkler system and water them from overhead, just as production nurseries do. There are at least two problems with this. One is that it is now illegal in most parts of Australia, simply because of the second problem: a high proportion of the water misses the containers.

The more usual method of surface watering is via a watering wand for plants on patios and other outdoor areas or via a small watering can for indoor plants. This obviously takes time and cannot be automated, but there are many advantages.

- You get to enjoy your plants as you water them.
- You notice problems such as attack by caterpillars or aphids, so you can take corrective action before there is much damage.
- Each plant can be given exactly what it needs.

See the end of Chapter 8 for information about using drippers to water plants in pots.

Sub-irrigation

Sub-irrigation is a general term used for systems that deliver water to plants via the bottom of the container. For successful use of sub-irrigation you must:

- Use pots that have drainage holes in their bases, not just at the bottom edges of their side walls.
- Use pots that are no more than about 20 cm tall. Water will not rise far enough up the potting mix in taller containers.
- Use a potting mix that has a relatively low air-filled porosity. The taller the containers to be used, the lower must be the air-filled porosity. For 20 cm deep mix, the air-filled porosity needs to be no higher than 14%; the mix should contain about 20% coir fibre dust.

The simplest way of watering from below is to have every pot sit in a saucer that is large enough to hold water for one or more days of plant use. This method is particularly useful for indoor plants.

Another method of sub-irrigation is to place the pot on top of a larger well of water with

Even if you don't have a self-watering pot, you can keep an indoor plant alive via wick watering while you are away.

For watering by sub-irrigation, there must be plenty of holes in the base of the pot.

a wick (old stocking or other water-absorbing synthetic cloth) running from inside the pot through a drainage hole and dangling in the water in the well. You can set this up yourself by using as a well any container that has a lid that is strong enough to hold the pot. All you need to do is to drill a hole in the lid. Water-well pots are a commercial variation on this theme.

Another method of sub-irrigation is to sit the pots on capillary matting which is either kept constantly moist or has water applied to it at intervals that keep the plants well supplied. This method is a bit trickier to set up than the other methods mentioned above, but it works well for all pots that are no deeper than about 20 cm. The capillary matting is installed on top of polyethylene sheeting which sits on a flat surface.

The fact that with sub-irrigation the potting mix is not being leached can be good or not so good for your plants, depending on the quality of your water and on how much fertiliser you use.

- Lack of leaching prevents the loss of nutrients from the mix, so you should use less fertiliser than you would with watering from above.
- But lack of leaching can allow the concentration of salts in the potting mix to get so high that plants are damaged.
- If your water has a very low concentration of salts, and you do not use excessive amounts of fertiliser, you should be able to maintain a plant with sub-irrigation for several years before you have any problems with salt.
- The saltier your water, the sooner it will be that you need to leach the mix. With any sub-irrigation system, you will soon see a white deposit of salts on the mix surface. They do no harm if they remain there, but if the build-up is heavy and starts to move down into the mix, it is time to leach. First, remove the pot from the sub-irrigation system. Then scrape away and discard the uppermost 1 cm or so of the mix with its salts. Pour about two pot volumes of water through the mix. Top up the mix. Return

it to the sub-irrigation system when drainage has stopped.

Fertilisers for plants in containers

If you are going to all the trouble of keeping up a supply of water to your plants growing in containers, you might as well have them looking good. You need to feed them, because the potting mix will not do this after the nutrients that came with it from the bag are used by the plant or have been washed out the bottom of the container. Information about fertilisers can be found in *Gardening Down-Under* (see Appendix 1).

A small amount of controlled-release fertiliser makes a lot of difference.

Testing environment. *Commiphora multijuga* (Perfumetree) growing in a crack in limestone.

TESTING POTTING MIXES

Measuring the air-filled porosity of a potting mix

The air-filled porosity of a mix is the percentage of its volume that is air just after it has stopped draining after being saturated with water. Here is a simple way that you can measure air-filled porosity (see Chapter 13 for interpretation).

Note: This method may look long and complicated, but it really is very simple. Once you get the hang of it, you will take no more than 10 minutes to measure the air-filled porosity of a mix, although that 10 minutes will be spread over a couple of hours.

You need the following:

- a cleaned, 600 mL milk carton
- an electric drill, sharp knife or hole punch of about 8 mm diameter, for making holes in the bottom of the carton
- a 9 L plastic bucket
- water (warmed in winter for your comfort)
- casserole dish or 4 L ice-cream container
- two pieces of wood or plastic, each of about 1.5 cm square section and about 8 cm long
- measuring jug of 250 mL capacity
- calculator.

Select a cleaned, undamaged 600 mL milk carton and carefully open out the top. Mark the inside of the carton at exactly 12 cm from the base. This will usually be just above the height at which the carton had been folded over. Make four holes in its base in positions such that you can close them with four fingers while holding the carton vertical with two hands. The holes should be about 8 mm diameter, or as big as your fingers will allow.

1. Fill moistened mix into the carton right to the top. Ideally, the mix should have been fairly moist, but not sloppy, for a few days before you do this test.

Drilling holes in the base of a milk carton.

2. Drop the carton vertically five times onto your workbench or other firm surface from a height of 5 cm. This consolidates the mix. If necessary, top up the mix to about a centimetre above the 12 cm mark.
3. Gently lower the carton of mix into water in a 9 L bucket. The height of water should be just a few millimetres below the top of the mix. Have the water low at the start and pour more into the bucket as needed. Make sure that the mix does not float up. Leave the carton of mix in the water for 30 minutes.
4. Carefully remove the carton from the water by slowly raising it vertically. Allow to drain for a few minutes. If necessary, add extra mix to the 12 cm mark then lower the carton into the water again.
5. Repeat Step 4.
6. Make a final adjustment of mix height by either adding more mix or gently scraping some out down to the 12 cm mark. Lower the carton of mix into the water and leave it for a further 10 minutes.
7. Reach down through the water and work your fingers underneath the carton until they seal the holes. Just before final sealing, make sure that the mix is saturated just to its surface.

Removing the saturated mix.

8. Raise the carton from the water. Allow water on the outside of the carton to drip off, while keeping the holes covered.
9. Place the carton on blocks in a shallow container such as a casserole dish or 4 L ice-cream container. Remove your fingers. Make sure that the holes can drain freely. Allow water to drain from the carton. The base of the carton must be horizontal (any tilting or squeezing will allow more water to drain out, so giving a falsely high reading of air-filled porosity).
10. Drainage from open mixes will be complete in 10 minutes, but it could take an hour or so from very 'heavy' mixes. The water draining from the mix is replaced by air. The volume of air that enters is the same as the volume of water that has drained into the container.
11. After drainage has stopped, remove the carton from the blocks, without tilting or squeezing the container. Measure the volume of water in the shallow container, or weigh it (1 mL water weighs 1 g).
12. Calculate or measure the volume of carton occupied by the mix. (A 12 cm height of mix in a standard 600 mL milk carton will have a volume of approx. 600 mL).
13. Calculate the air-filled porosity of the mix with the formula:

    Air-filled porosity (volume %)

    $$= \frac{\text{volume of water drained (mL)} \times 100}{\text{volume of mix (mL)}}$$

Example: 120 mL of water drains from 600 mL of mix

$$\text{Air-filled porosity} = \frac{120 \times 100}{600} = 20\%$$

That is, 20% of the volume of the mix was air immediately after it had stopped draining.

Water-holding capacity

If you want to know the amount of water held by your mix, all you need to do is this.

At Step 11 of the air-filled porosity determination, place the carton of drained potting mix on kitchen scales.

14. Record its weight (W1).
15. Tip all of the potting mix into a large tray.
16. Weigh the empty carton (W2).
17. Spread the mix out in the tray and sit the tray in the sun until the mix has completely dried.

Testing the wettability of a potting mix.

18. Weigh the dry potting mix (W3).

The water-holding capacity of the mix is

$$\frac{(W1 - W2 - W3) \times 100}{(W1 - W2)}$$

For example, if the wet mix plus carton weighed 800 g, the carton weighed 20 g and the dried mix 380 g, the water holding capacity of this mix is $(800 - 20 - 380) \times 100 \div (800 - 20) = 400 \times 100/780 = 51\%$. In other words, water made up 51% of the weight of the just-drained mix.

Wettability of a potting mix

You can check as follows for the need to add a wetting agent to a potting mix.

- Dry some of the mix by spreading it on a piece of paper and leaving it in the sun.
- Fill the dried mix into a small dish, such as an aluminium foil pie dish.
- Make a shallow depression in the centre of the mix with a standard light globe, tennis ball or spoon.
- Gently add 10 mL of deionised water or rainwater to the centre of the depression.
- Record the time taken for the water to soak into the mix. The water is regarded as having soaked in when slight tilting of the dish gives no movement of water in the wet patch.

Add a wetting agent to the potting mix if it took longer than 20 seconds for the water to soak in.

APPENDIX 1 SOURCES OF EXTRA INFORMATION

Chapter 1

Climate change

CSIRO and Australian Bureau of Meteorology: www.csiro.au/resources/ps3j6.html. This site has details on projected effects of global warming on temperatures and rainfall throughout Australia.

Flannery T (2005). *The Weather Makers: The History and Future Impact of Climate Change.* Text Publishing: Melbourne.

Hamilton C (2007). *Scorcher: The Dirty Politics of Climate Change.* Black Inc. Agenda: Melbourne.

Intergovernmental Panel on Climate Change: www.ipcc.ch. This site includes the latest reports on climate change.

www.sustainablehouse.com.au. This site includes many ideas for reducing your 'carbon footprint' and for maximising rainwater use.

Benefits of urban greenery

Cooperative Research Centre for Irrigation Futures: www.irrigationfutures.org.au. Includes forthcoming report: 'The social and environmental benefits of urban irrigation in open public spaces and the economic value associated with these benefits'.

Chapter 2

Australian plants

Elliot WR and Jones DL. *Encyclopaedia of Australian Plants.* Lothian: Melbourne. There are nine volumes and some supplements. Volume 9 will not be published before late 2008.

Peate N, Macdonald G and Talbot A (2006). *Grow What Where.* (3rd edn). Bloomings Books: Melbourne. This has extensive lists of Australian native plants according to their various requirements.

Snape D (2002). *The Australian Garden: Designing with Australian Plants.* Bloomings Books: Melbourne. This is a treasure-trove of design ideas for Australian gardens.

http://users.chariot.net.au/~hharvey/APSquery.html. A searchable database of Australian native plants according to plant type, soil and climatic preferences. It has been specifically developed for South Australia, but is also relevant to south-west Western Australia and Victoria.

Mediterranean plants

Morgan D (2004). *Succulents for Mediterranean Climate Gardens.* Rosenberg Publishing: Dural.

Nottle T (1996). *Gardens of the Sun.* Timber Press: Portland, Oregon.

Nottle T (2004). *Plants for Mediterranean Climate Gardens.* Rosenberg Publishing: Dural.

This book features many plants that can be grown with minimal extra water.

Perry B (1992). *Landscape Plants for Western Regions: An Illustrated Guide to Plants for Water Conservation*. Land Design Publishing: Claremont, CA.

Savewater®Alliance, Armadale, Victoria: www.savewater.com.au. Includes a plant selector for Australia.

Windust A (2003). *Waterwise House and Garden*. Landlinks Press: Melbourne. This has lists of both Australian and exotic plants of high drought tolerance.

Weeds

Australian Weeds Committee, Launceston, Tasmania: www.weeds.org.au.

Cooperative Research Centre for Australian Weed Management, Adelaide, South Australia: www.weeds.crc.org.au.

Queensland Government, Natural Resources and Water: www.nrw.qld.gov.au. Has a list of Declared plants (weeds) for Queensland.

Richardson RG and FJ, Meredith, Victoria: www.weedinfo.com.au.

Chapter 7

Rain Harvesting, Archerfield, Queensland: www.rainharvesting.com.au. Comprehensive information about tanks and the hardware needed to harvest rainwater.

Lists of plants that are suitable for particular areas

Association of Societies for Growing Australian Plants: http://asgap.org.au.

Australian Plants Society, South Australian region: www.australianplantssa.asn.au.

Brisbane City Council: www.ourbrisbane.com.

Melbourne Water: www.conservewater.melbournewater.com.au.

Ornamental Plant Conservation Association of Australia: www.rbg.vic.gov.au/opcaa. This site maintains collections of ornamental plants that might otherwise disappear. You can purchase rare plants through them.

Renaissance Herbs Pty Ltd (1997): www.renaissanceherbs.com.au. This site has lists of herbs according to water needs.

Sydney Water: www.sydneywater.com.au/savingwater/inyourgarden/plantselector.

University of Melbourne, Burnley College: www.horticulture.unimelb.edu.au/info/plntdrct.htm. Information about the Burnley Plant Directory. This has descriptions and images of over 3000 plants that are suitable for Australian gardens. Version 2 is due to be released in 2008.

The Water Corporation (2003–2006): www.watercorporation.com.au.

Chapter 8

Irrigation Australia, Hornsby, New South Wales: www.irrigation.org.au.

Smart Approved Water Mark: www.smartwatermark.org. This site lists water-related products that have been assessed independently and approved as being able to reduce water use.

Chapter 10

Australian Institute of Horticulture: www.aih.org.au.

Australian Institute of Landscape Architects: www.aila.org.au.

Australian Institute of Landscape Designers and Managers: www.aildm.com.au.

Australian Society of Garden Designers: www.asgardendesigners.org.

www.landscapingaustralia.com.au. For links to state landscaper associations.

Nursery and Garden Industry Australia: www.ngia.com.au. With links to state associations.

www.plant.id.au. Has a listing of associations related to urban horticulture, with links to their members.

Chapter 13

Handreck K and Black N (2005). *Growing Media for Ornamental Plants and Turf* (3rd edn). University of New South Wales Press: Sydney. This book has extensive technical information about potting mixes and the growing of plants in them.

General

Greenpages Australia, Surry Hills, New South Wales: www.greenpagesaustralia.com.au. This site has extensive lists of companies and organisations that can provide products or information about all things green.

Handreck K (2001). *Gardening Down-Under* (2nd edn). Landlinks Press: Melbourne.

Open Garden, New Gisborne, Victoria: www.opengarden.org.au. This site lists all Australian gardens that are open for inspection and inspiration over each coming year.

Sustainable Gardening Australia, Bulleen, Victoria: www.sgaonline.org.au. This site has discussion forums and information about many aspects of gardening.

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